אני יודע מה עשית בפענוח האחרון: התקפות ערוצי צד על מחשבים אישיים

I Know What You Did Last Decryption: Side Channel Attacks on PCs

Daniel Genkin

Technion and Tel Aviv University

joint work with

Lev Pachmanov
Tel Aviv University

Itamar Pipman
Tel Aviv University

Adi Shamir
Weizmann Institute of Science

Eran Tromer
Tel Aviv University

Side channel attacks

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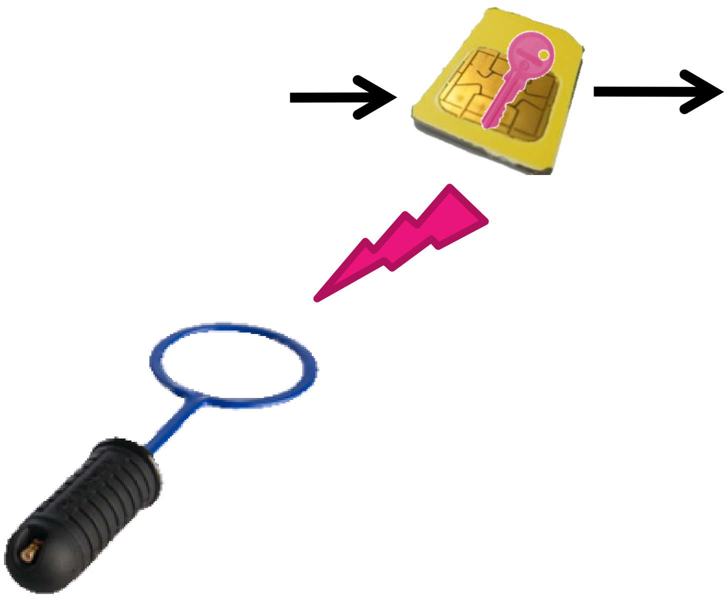

electromagnetic

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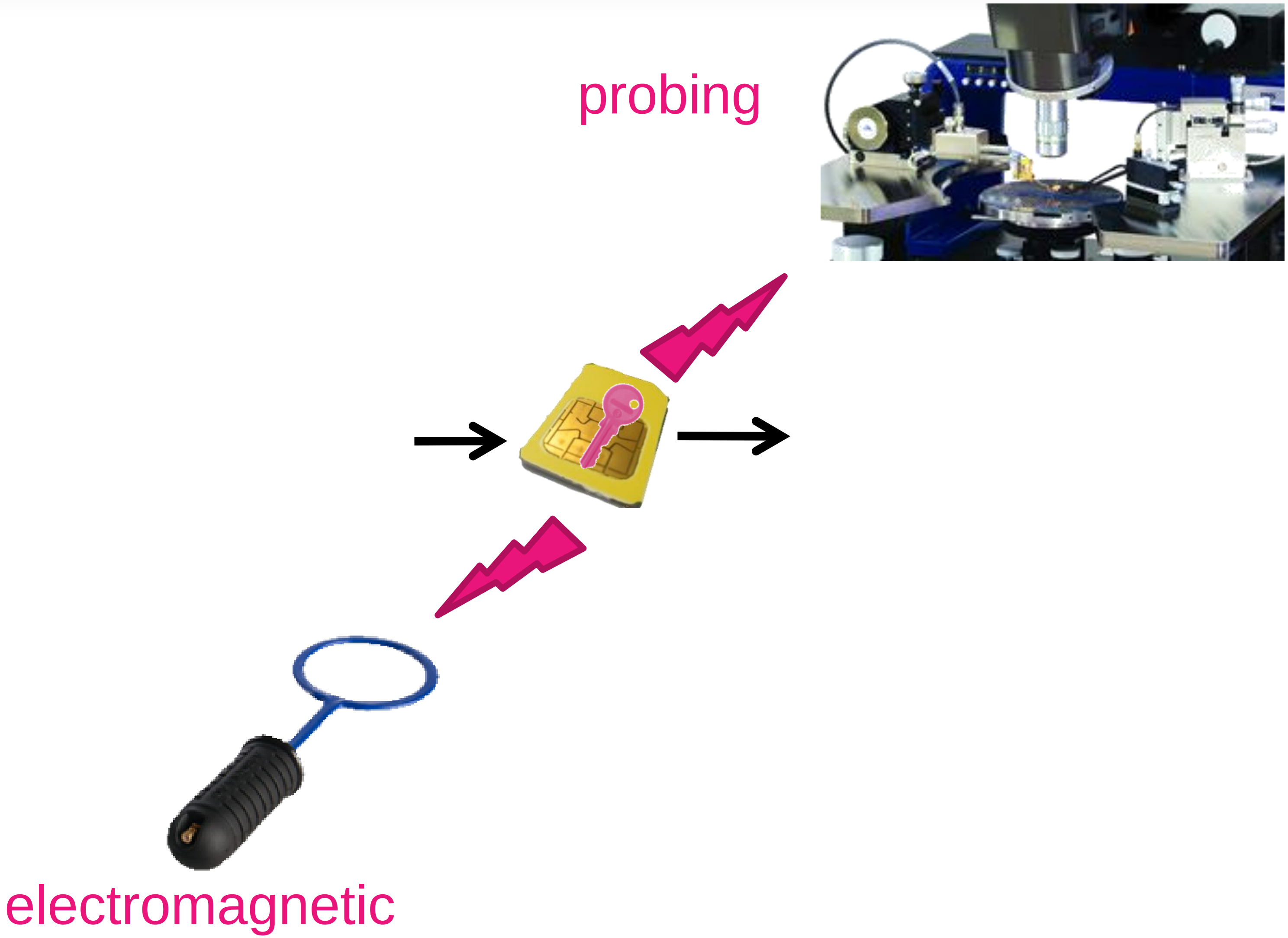

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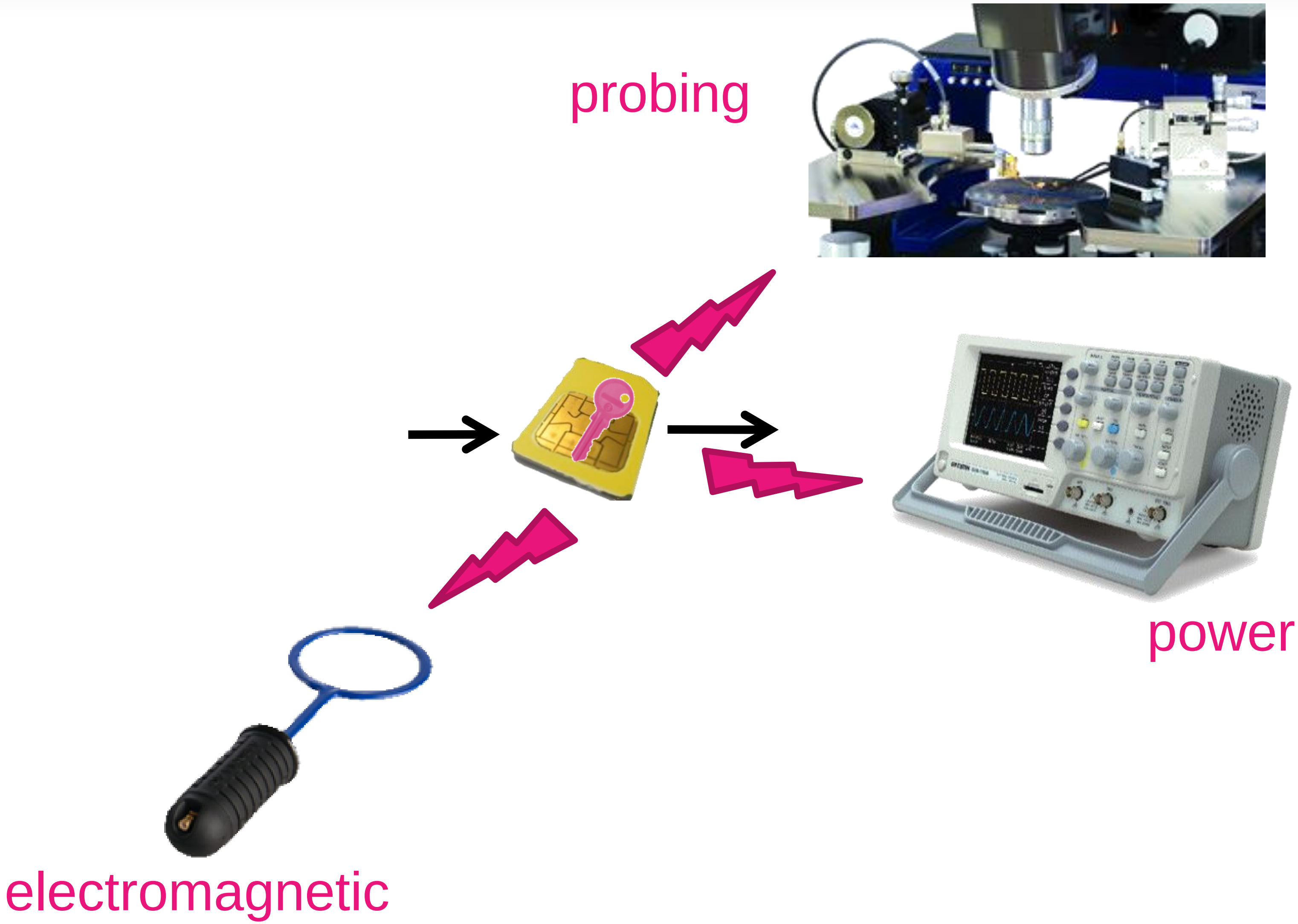

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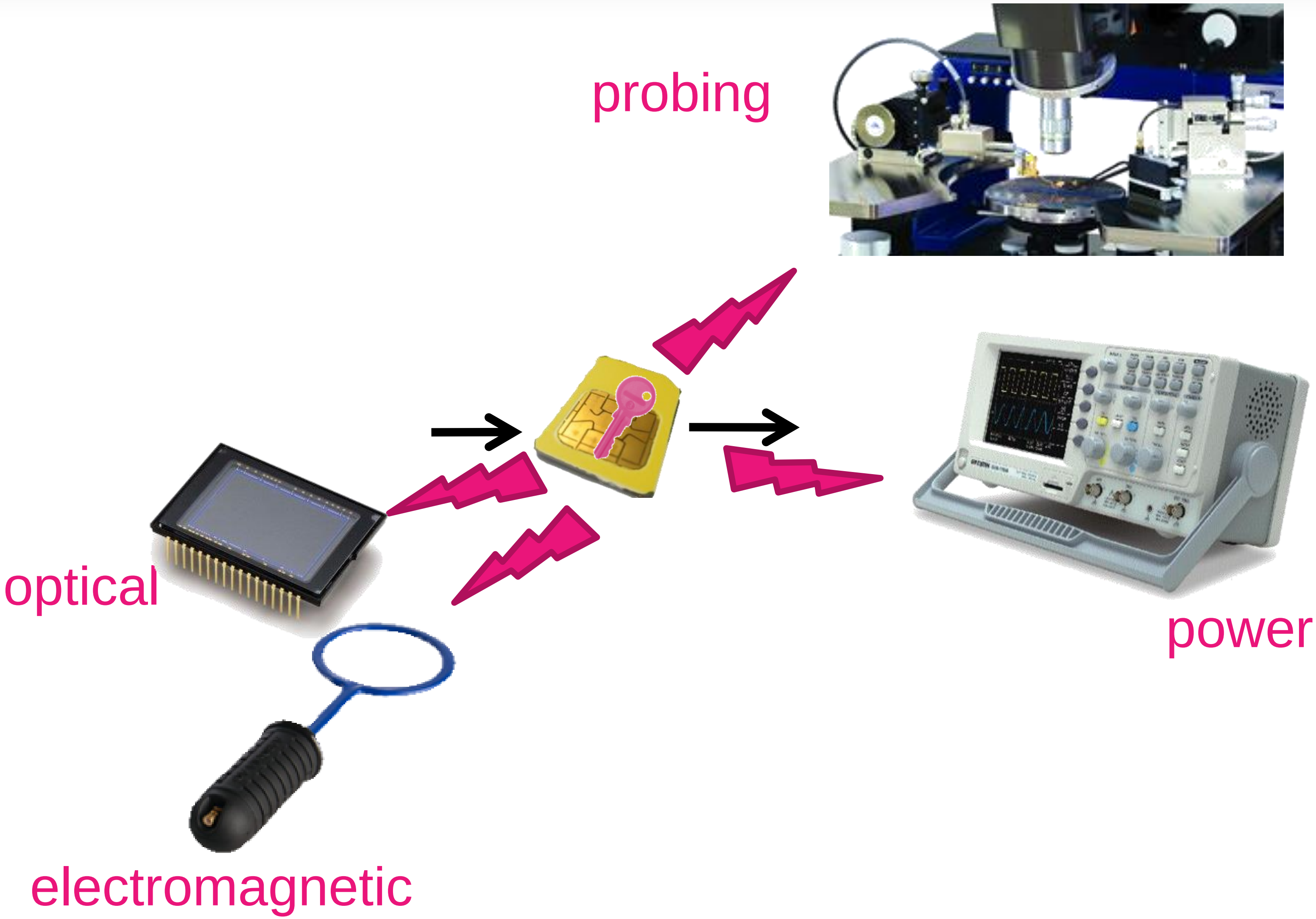

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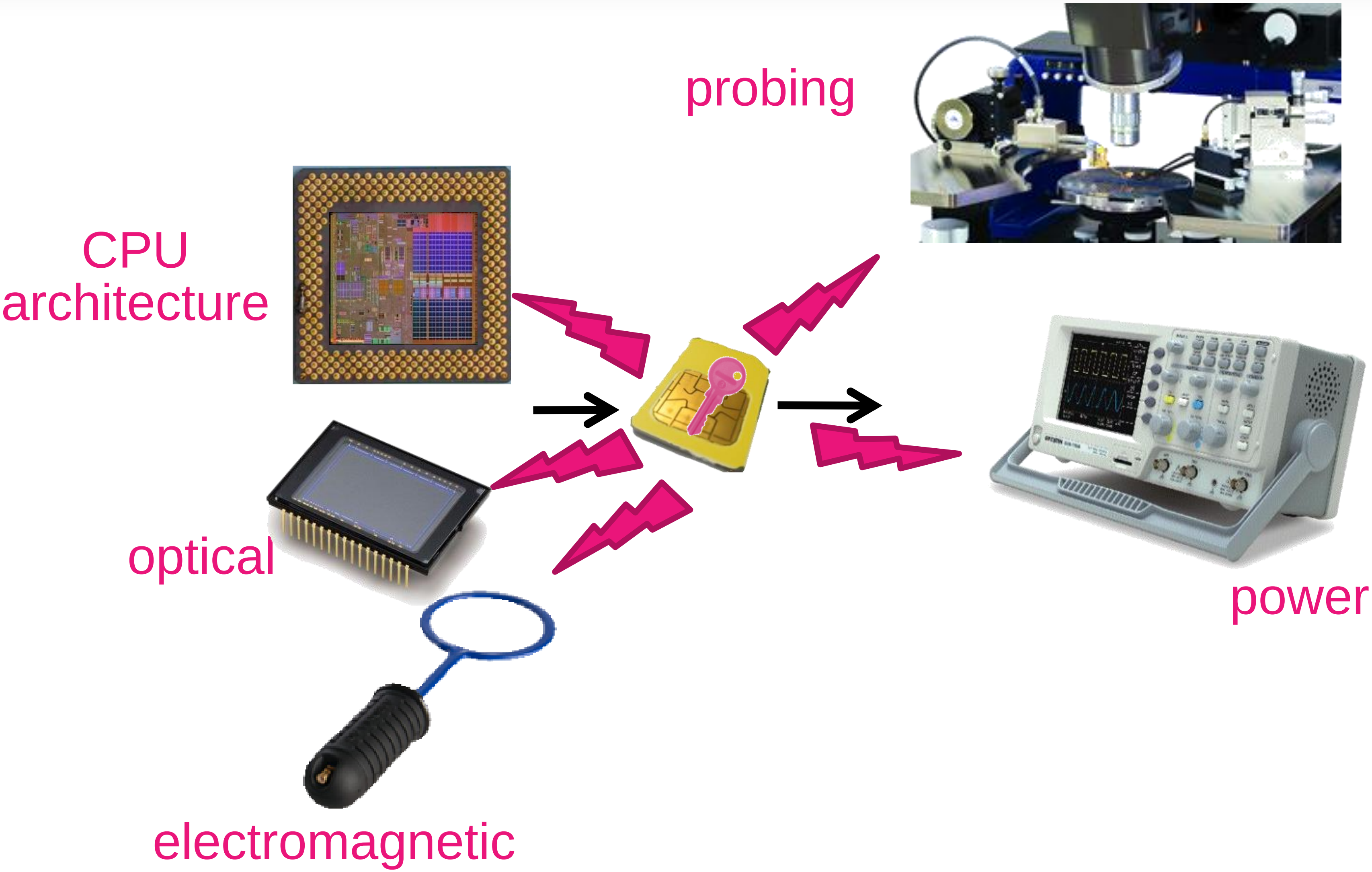

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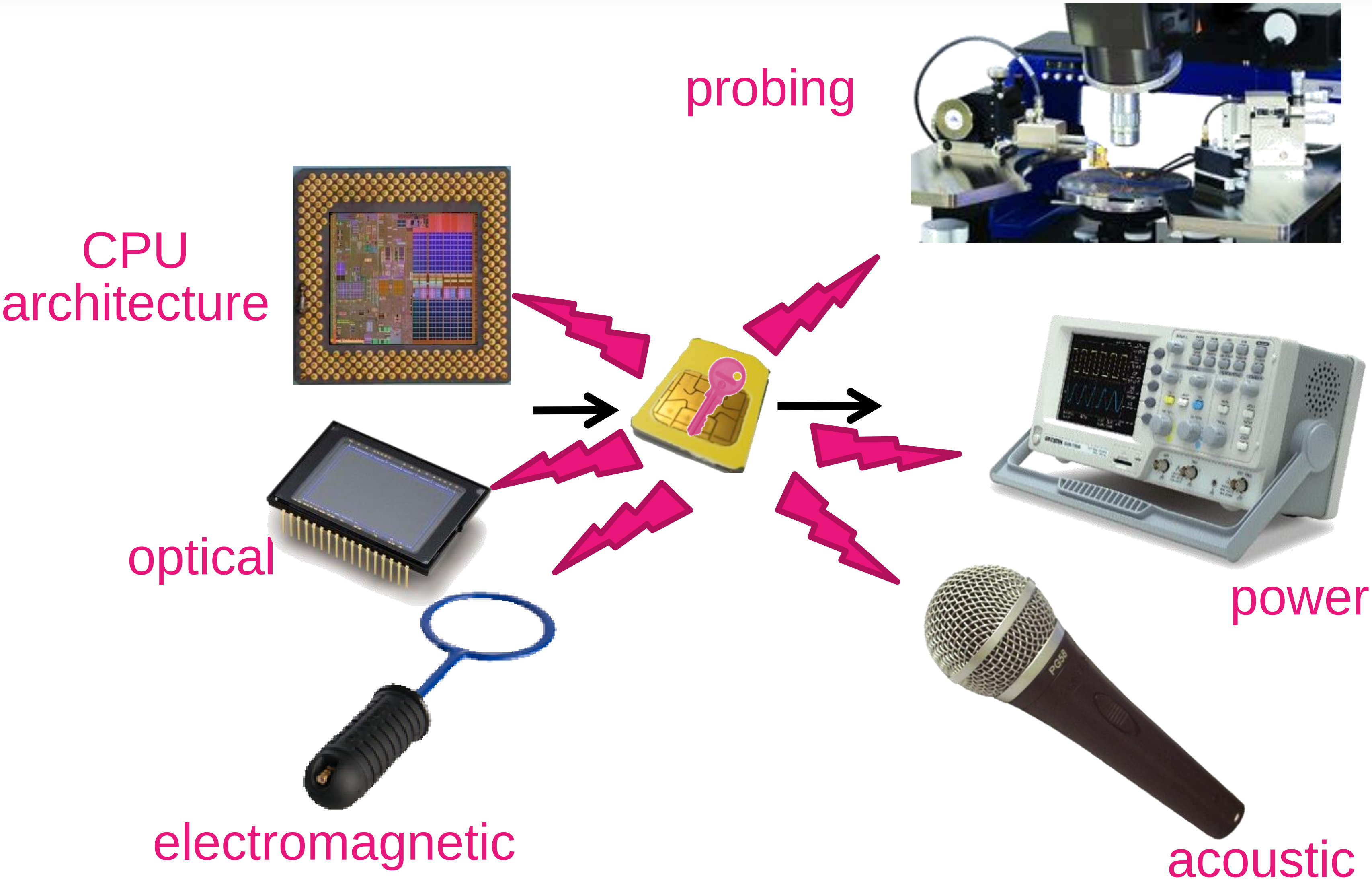

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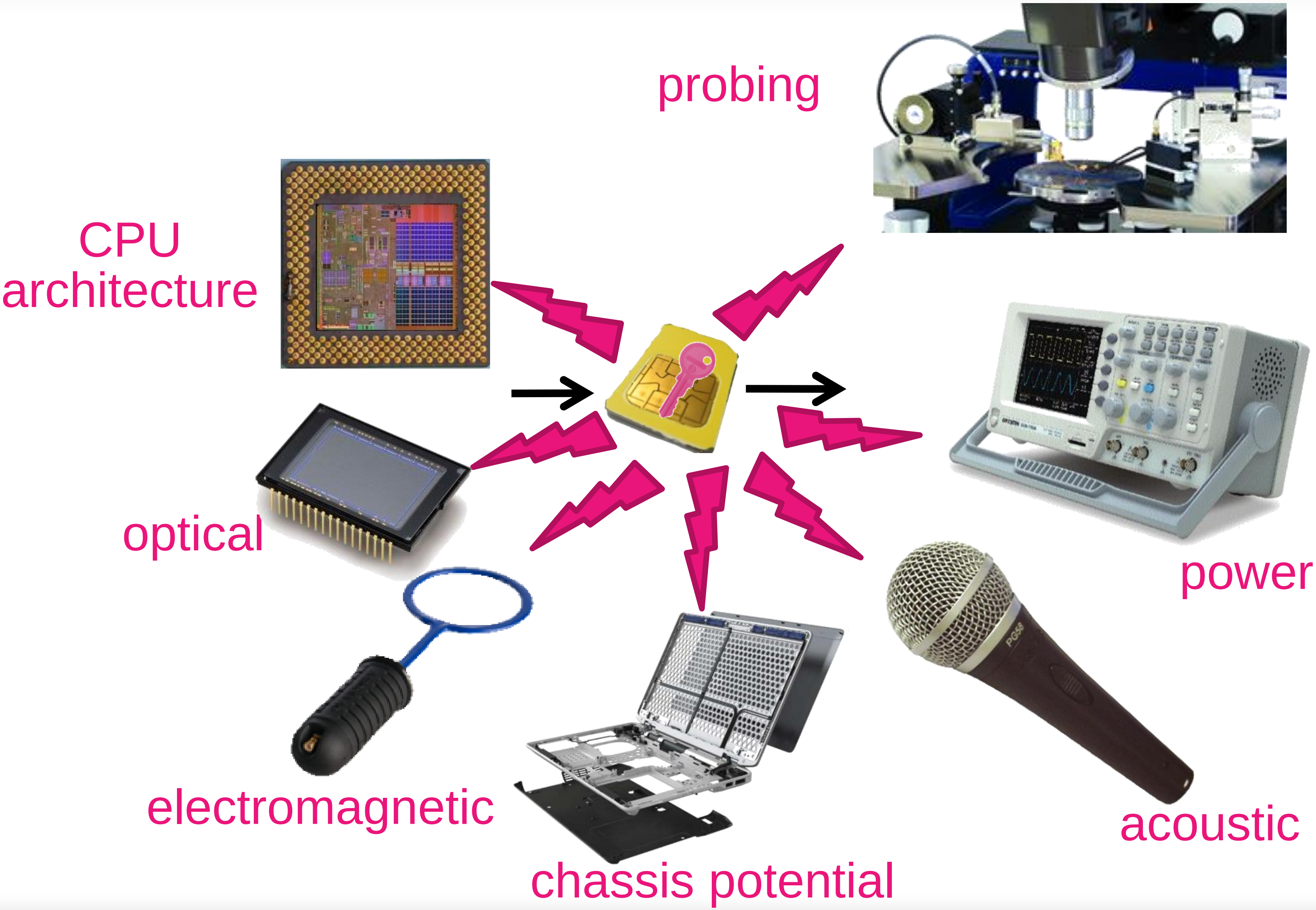

Side channel attack example

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100MHz

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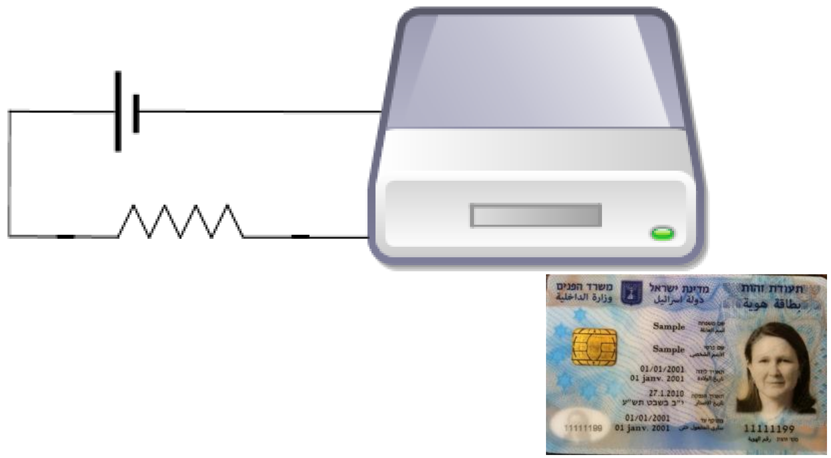

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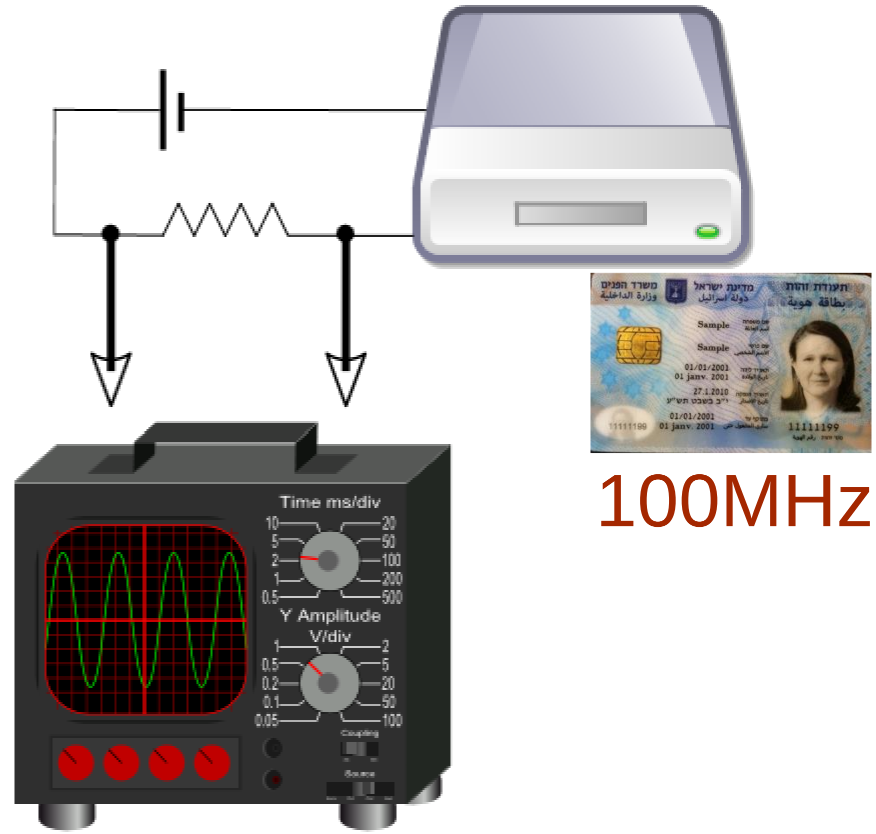

100MHz

400MHz

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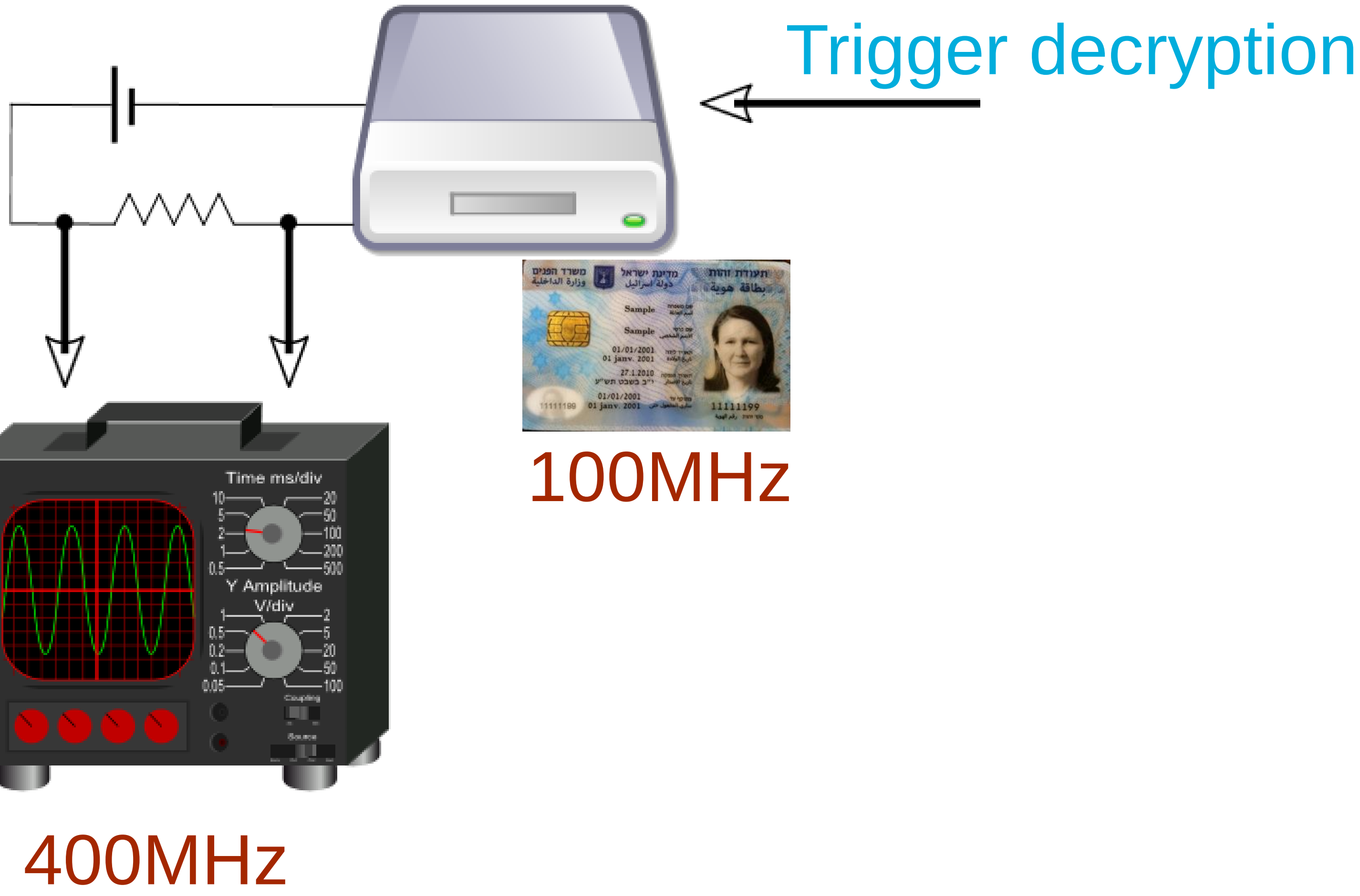

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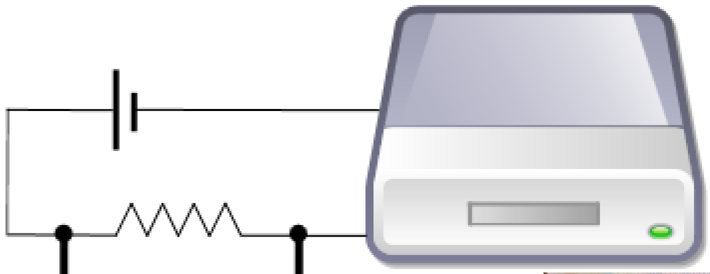
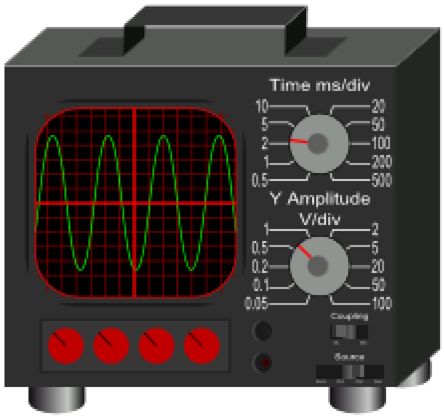


Trigger decryption

100MHz



Obtain traces

400MHz

Side channel attack example

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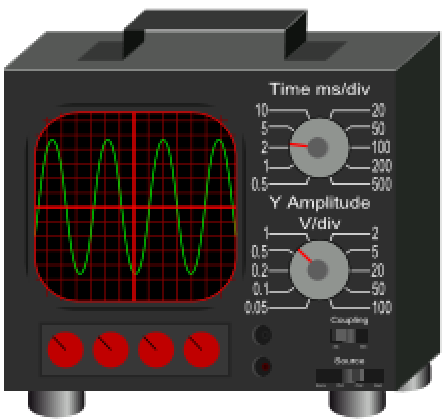

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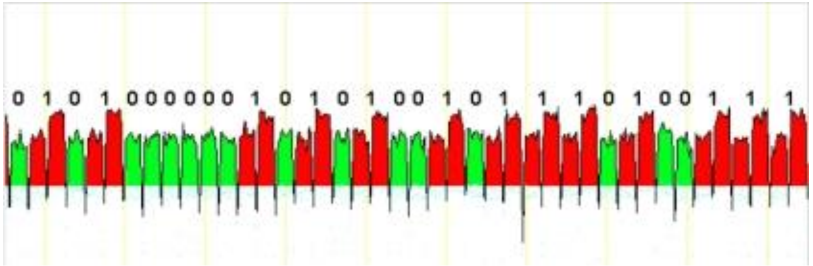

400MHz

Traditional side channel attacks methodology

1. Grab/borrow/steal device

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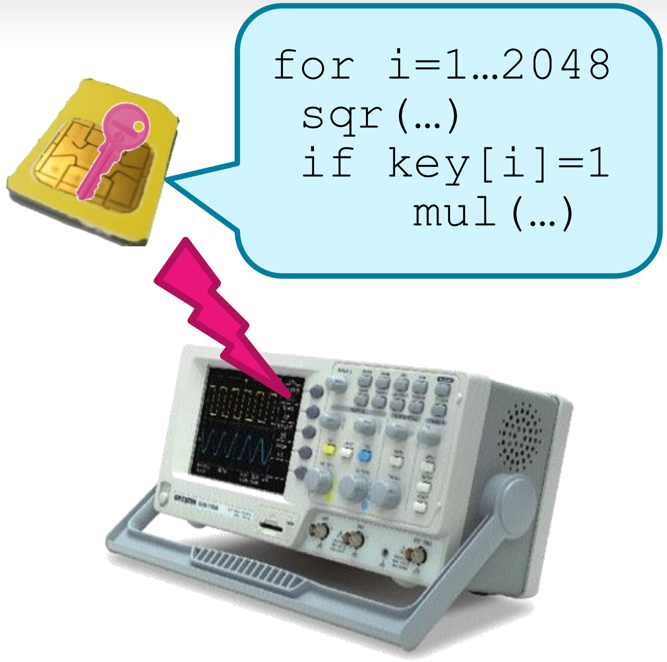
2. Find key-dependent instruction

```
for i=1…2048
 sqr(…)
 if key[i]=1
    mul(…)
```

Traditional side channel attacks methodology

1. Grab/borrow/steal device
2. Find key-dependent instruction
3. Record emanations using high-bandwidth equipment (> clock rate , PC: >2GHz)



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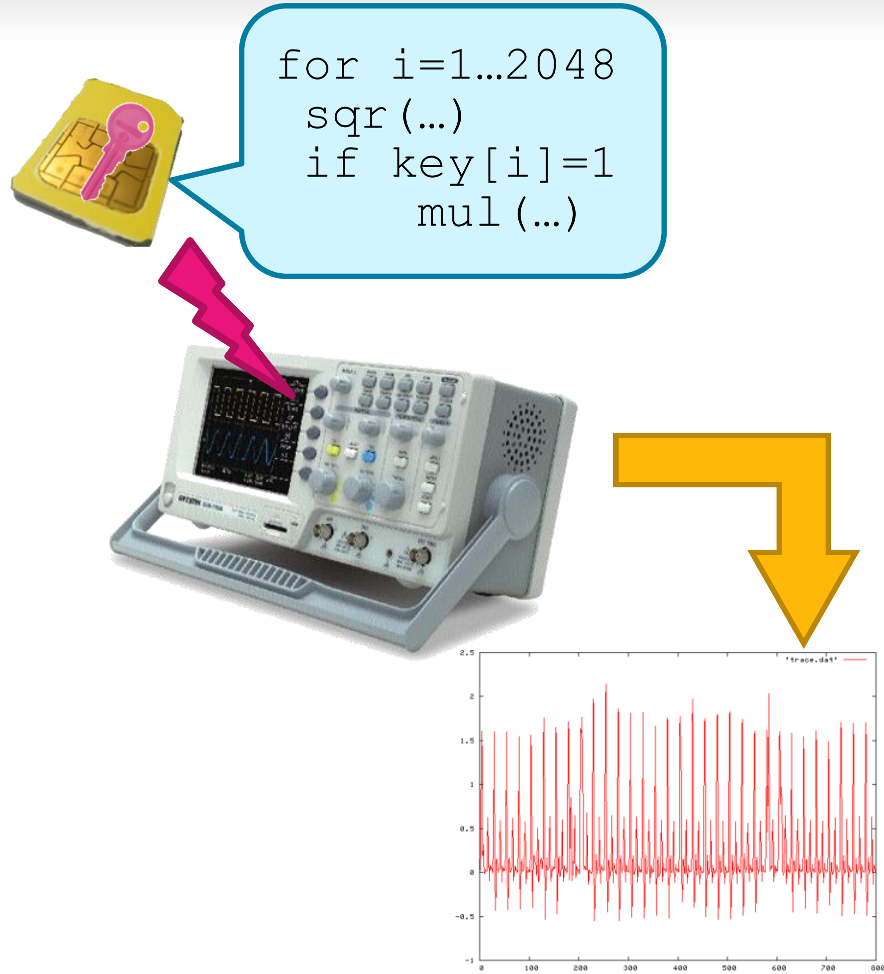

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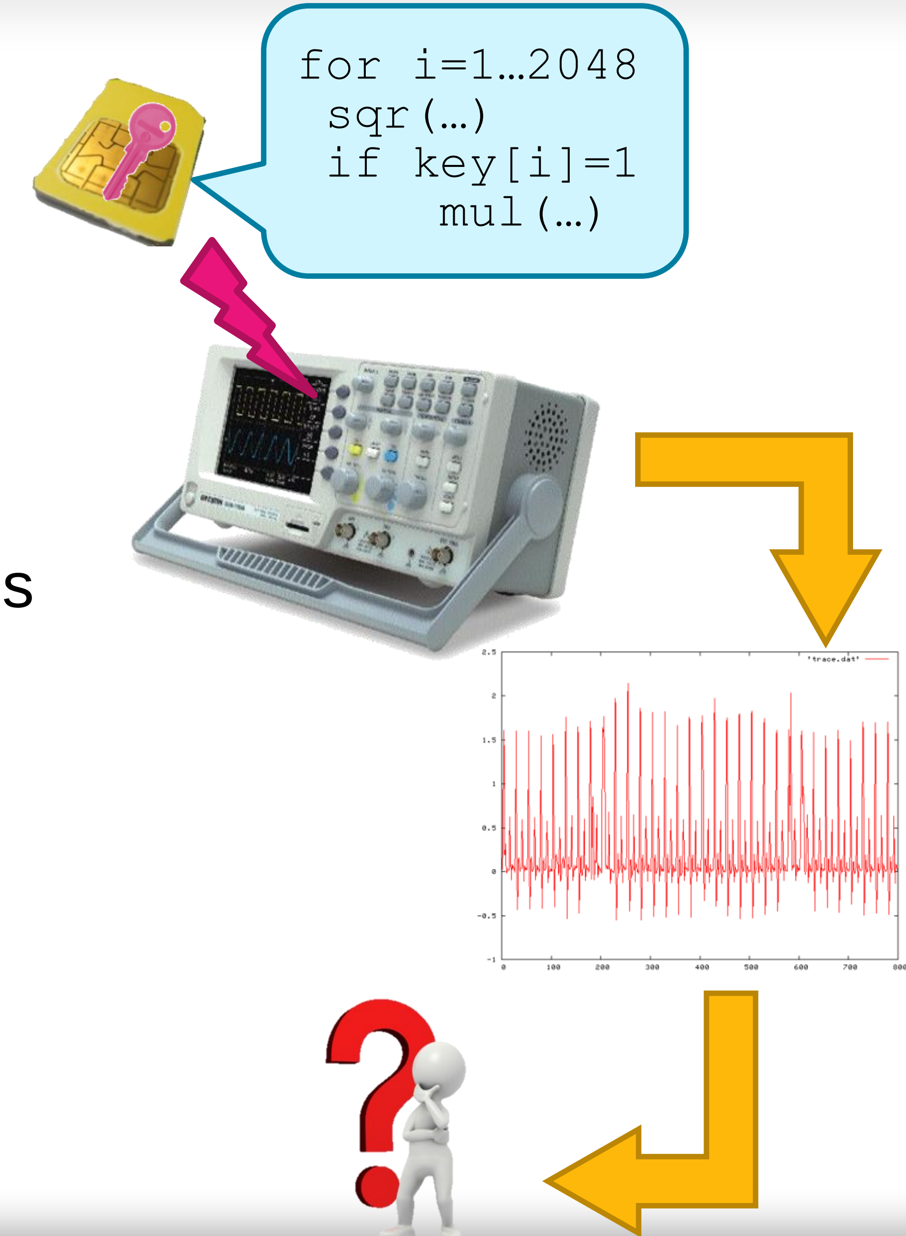

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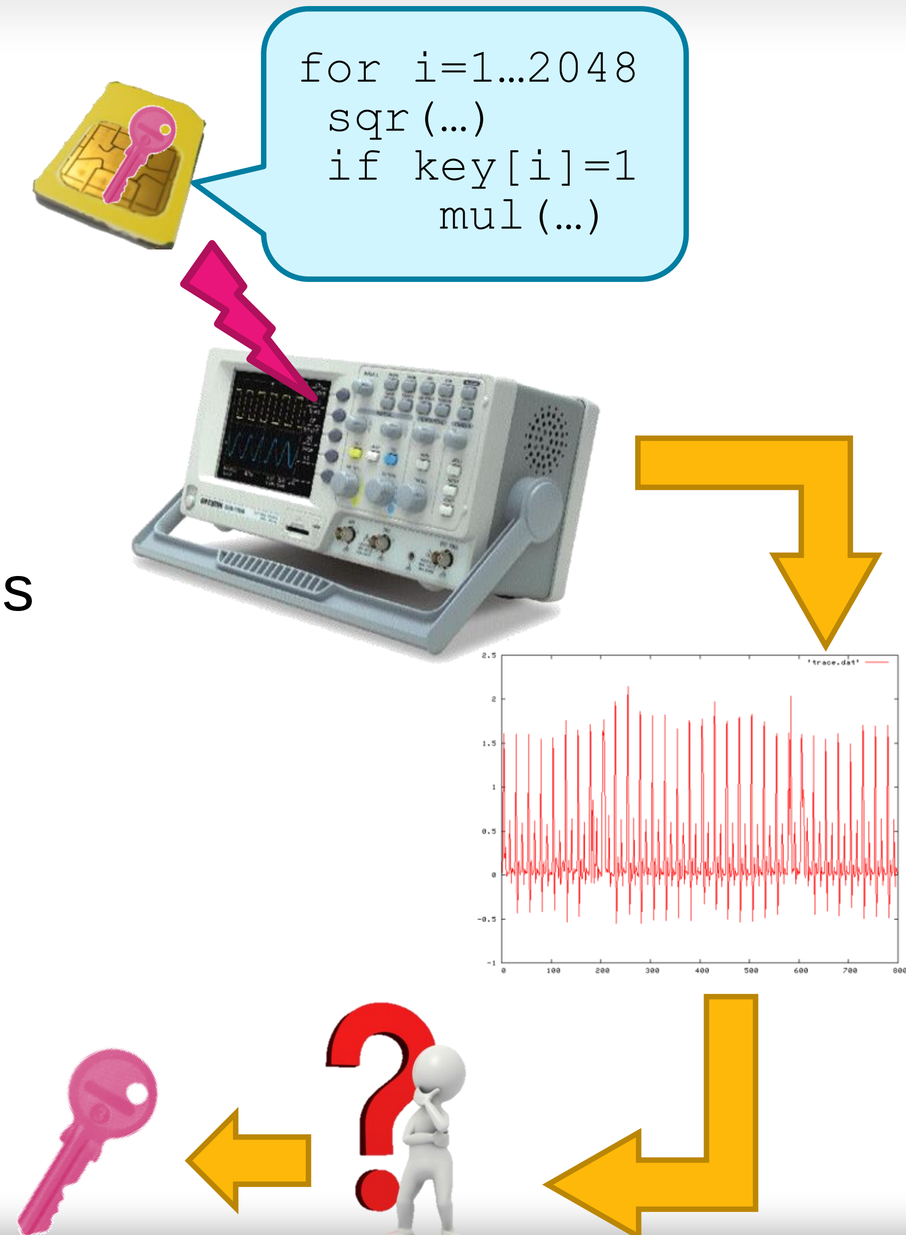

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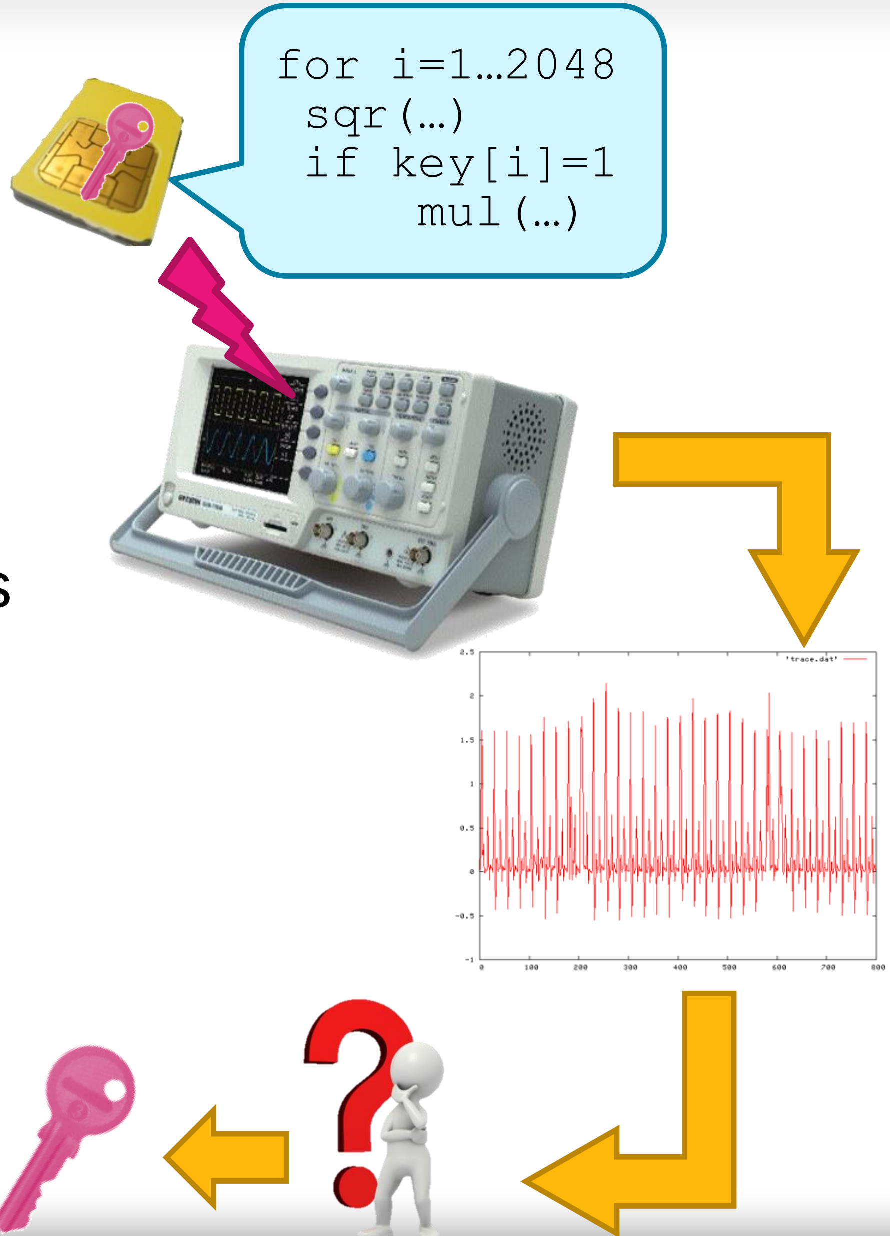

Hard for PCs 

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vs.

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Measuring a 2GHz PC requires expansive and bulky equipment (compared to a 100 MHz smart card)

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100,000$ 1,000$

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100,000$

vs.

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Complex electronics running complicated software (in parallel)

vs.

New channel:
chassis potential

Ground-potential analysis

- **Attenuating EMI emanations**
  “Unwanted currents or electromagnetic fields?
  Dump them to the circuit ground!”
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Computation

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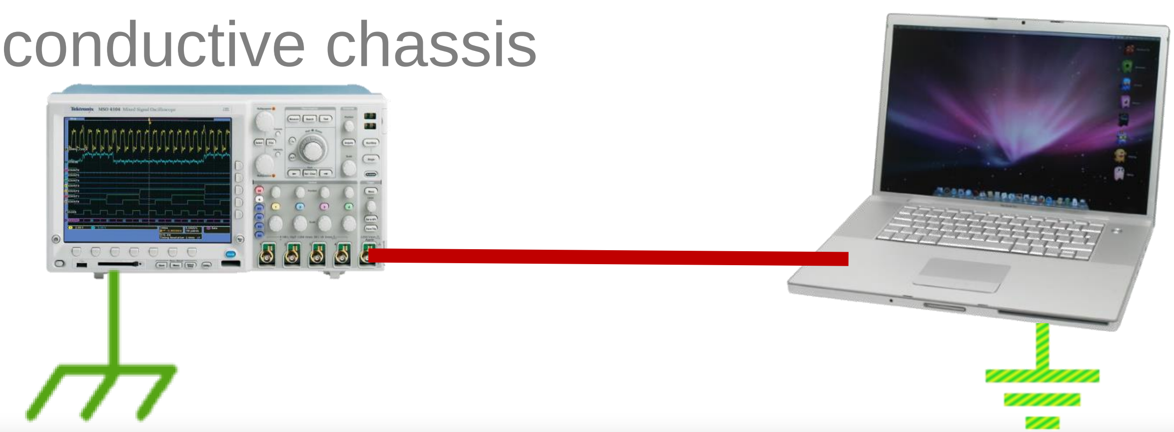

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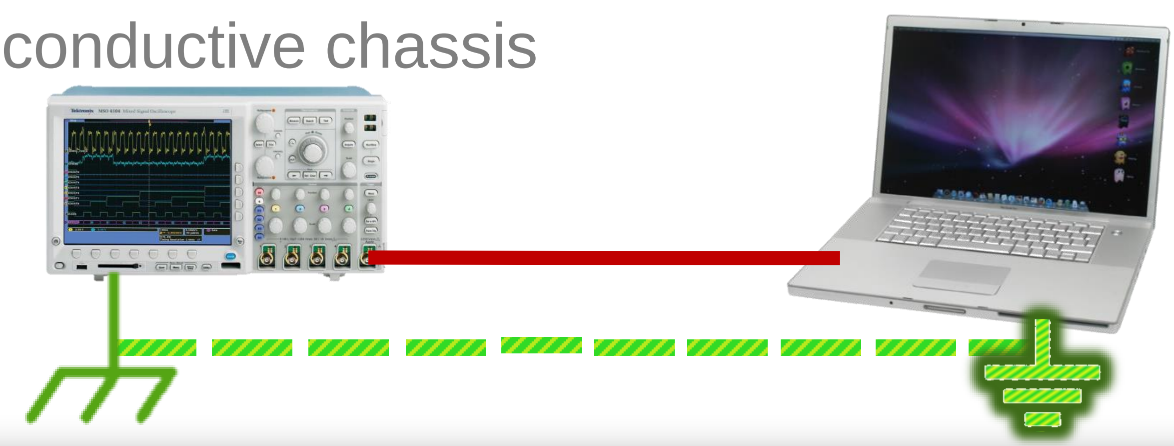

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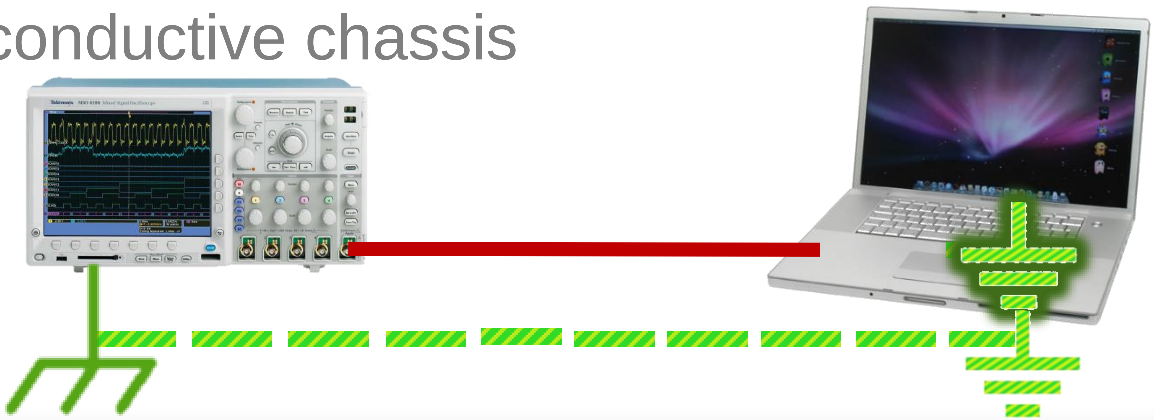

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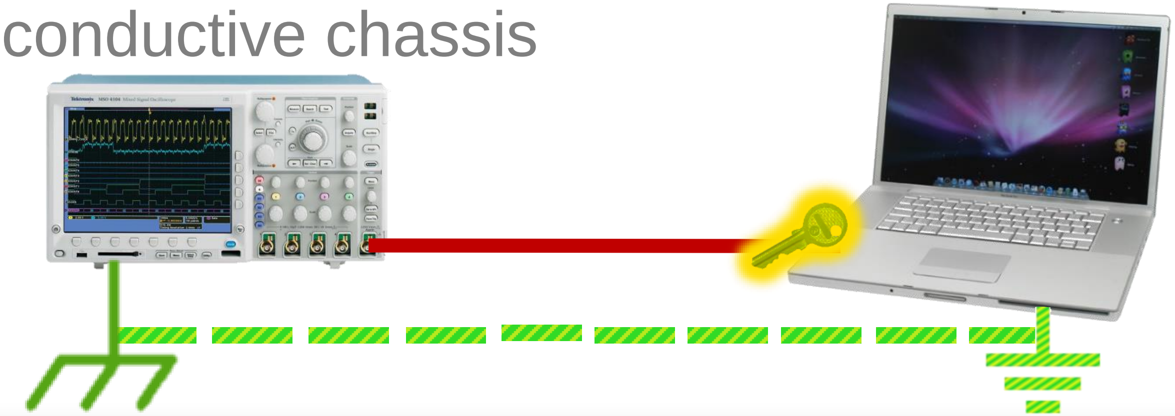

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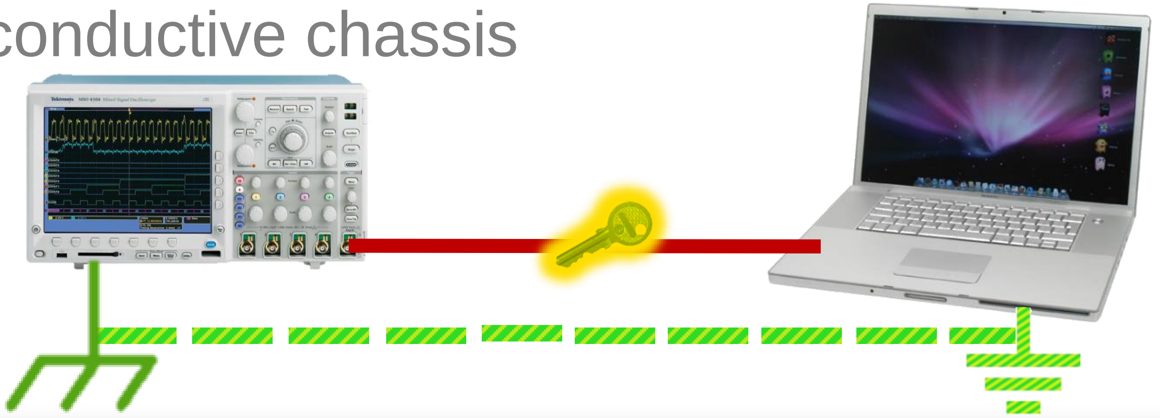

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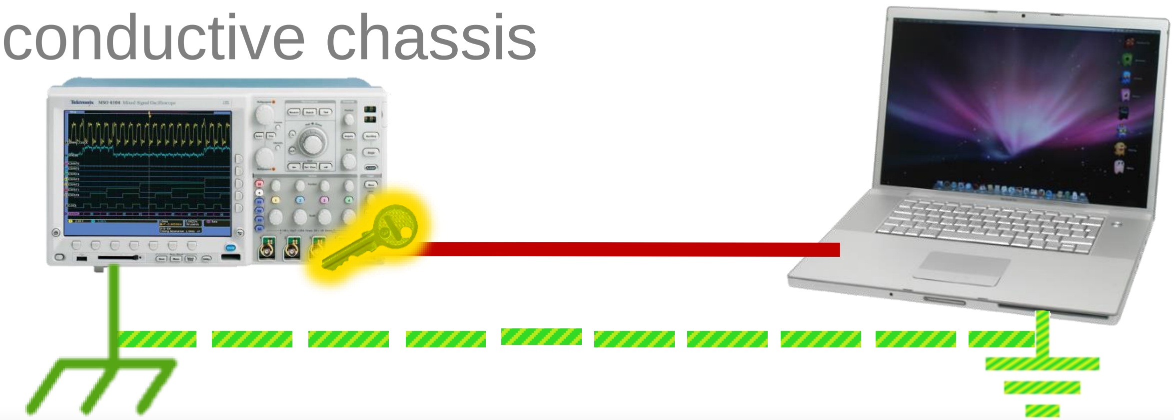

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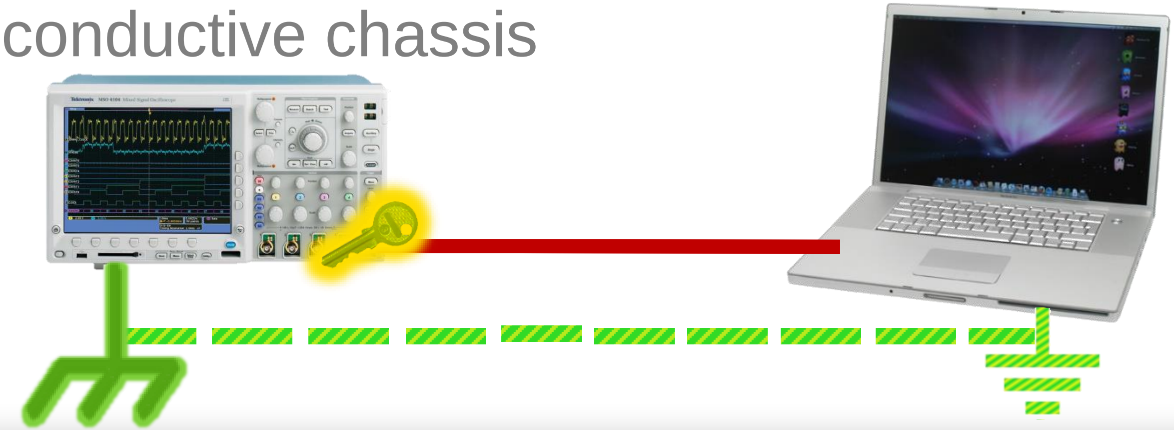

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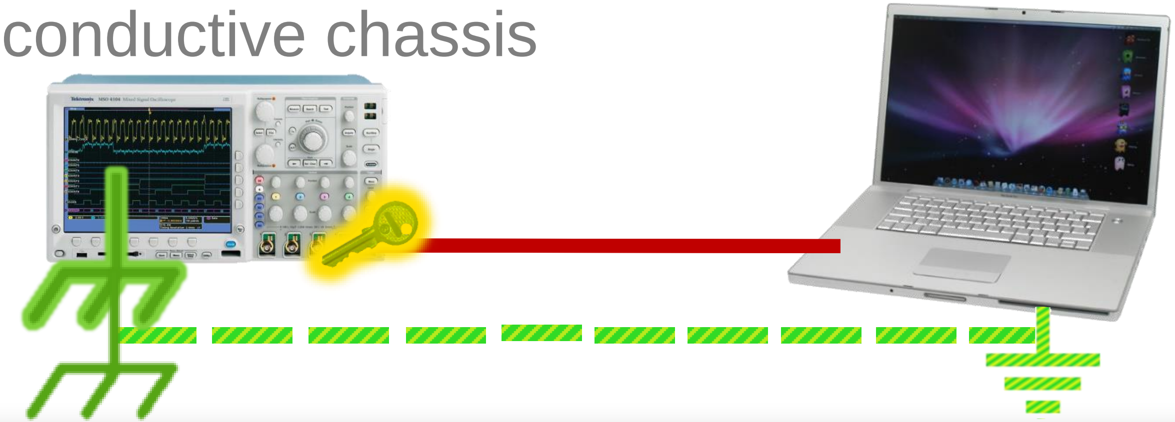

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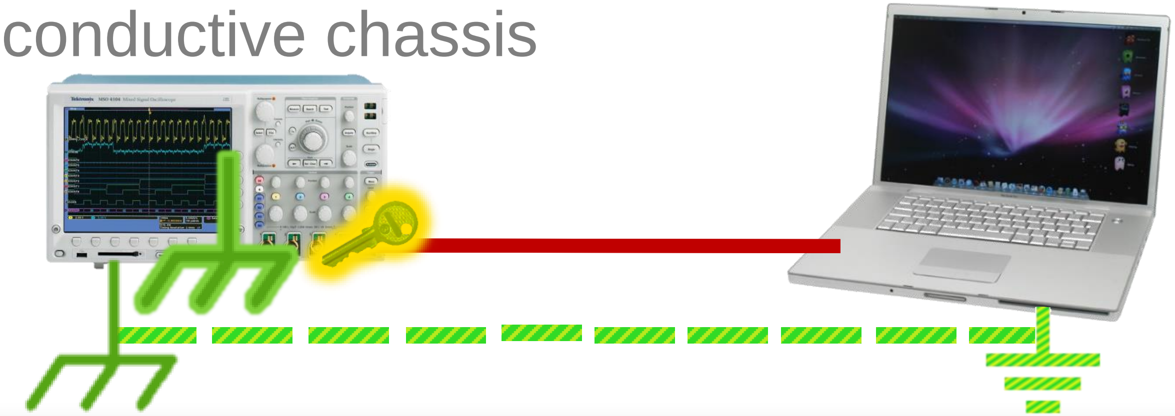

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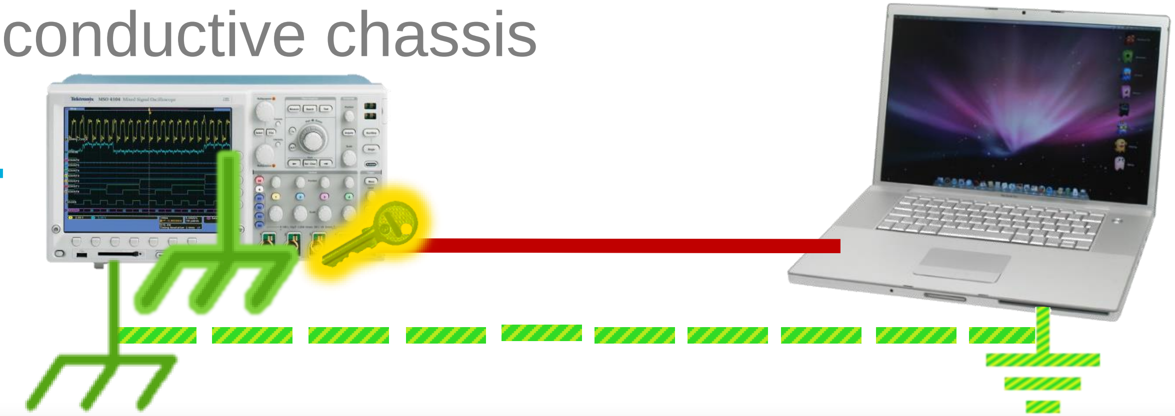
Key = 101011…



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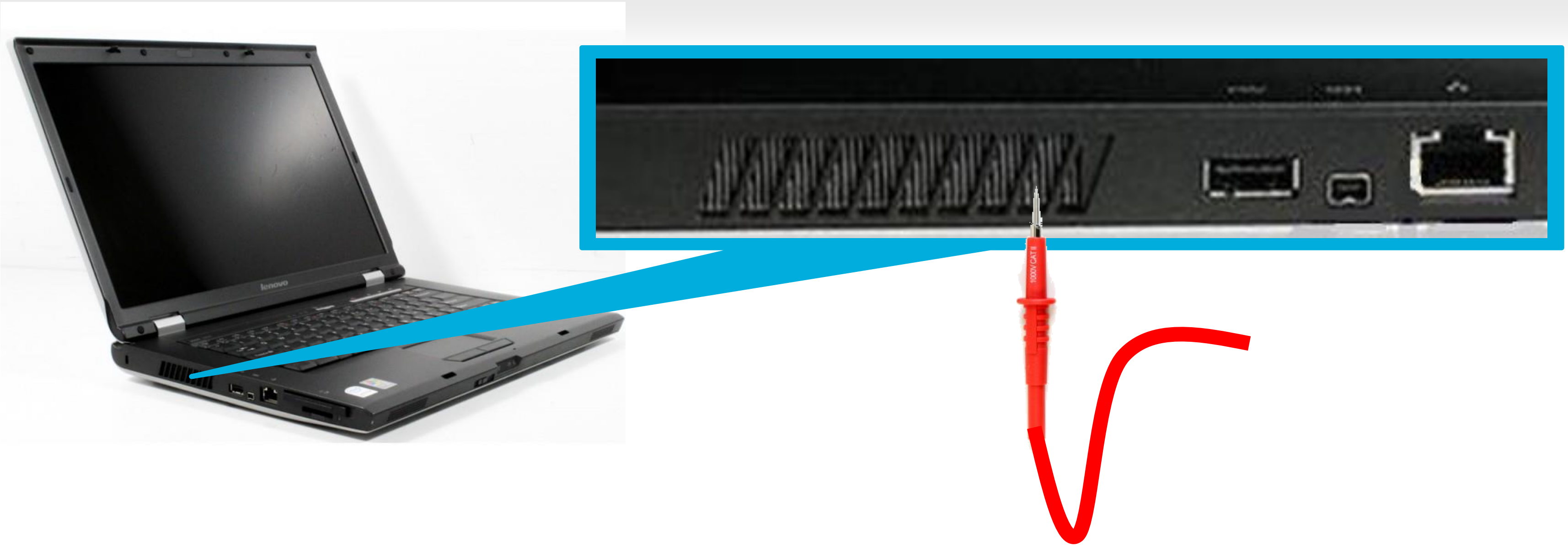

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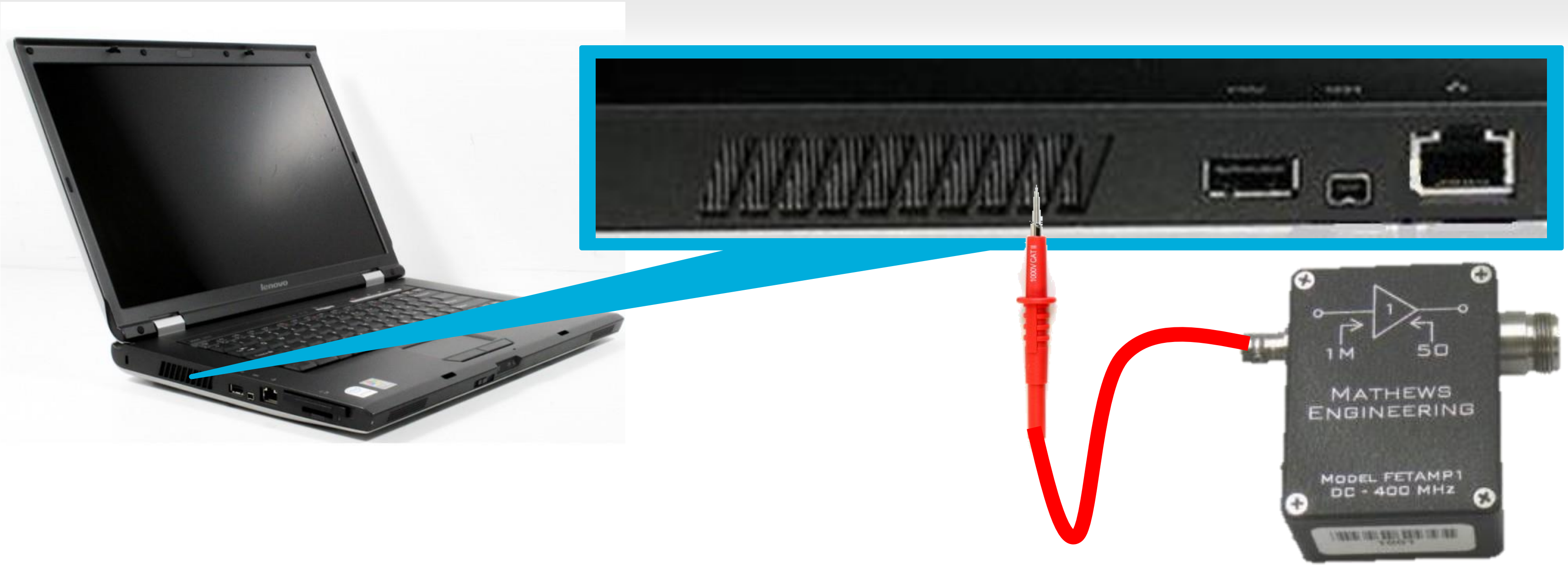

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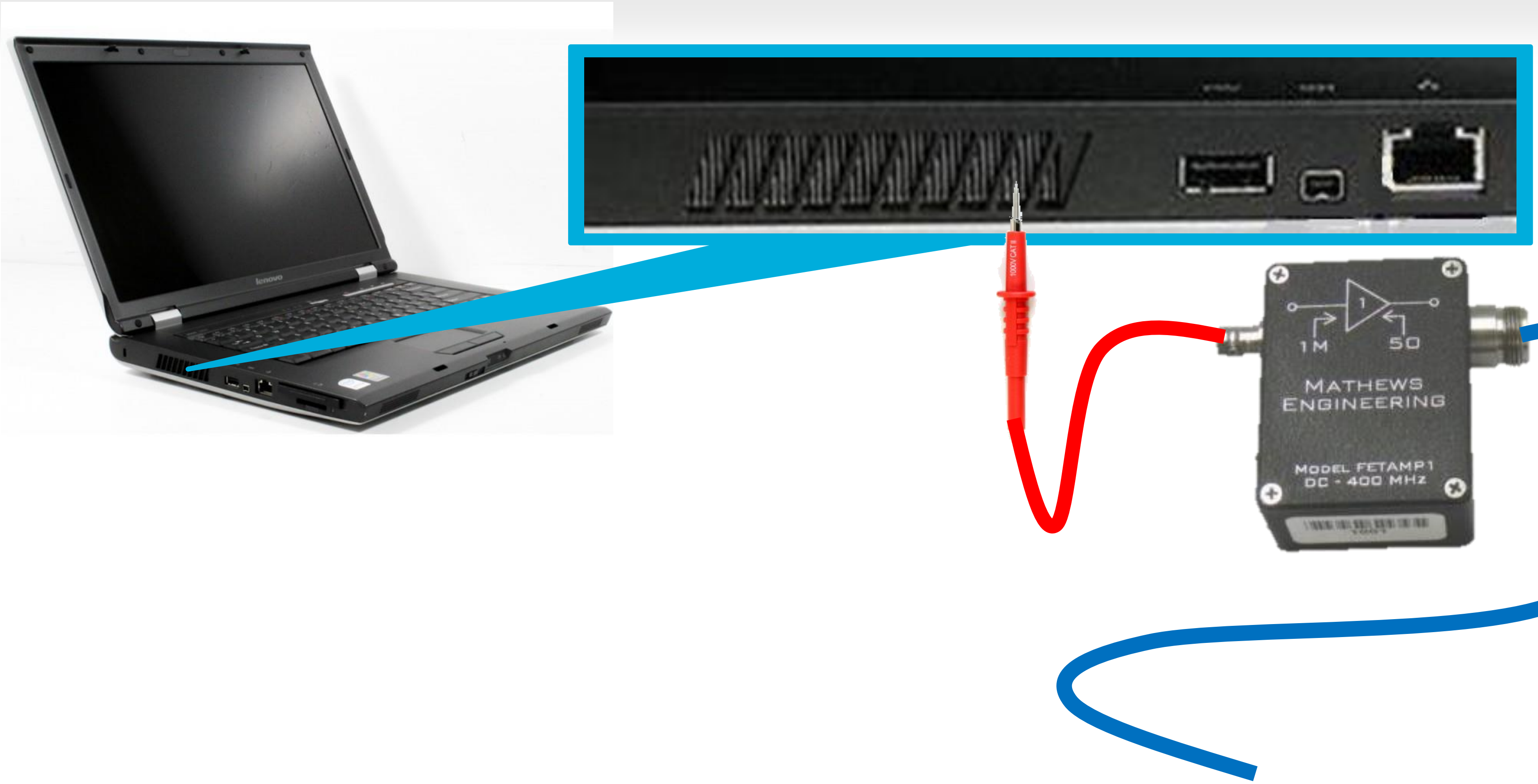

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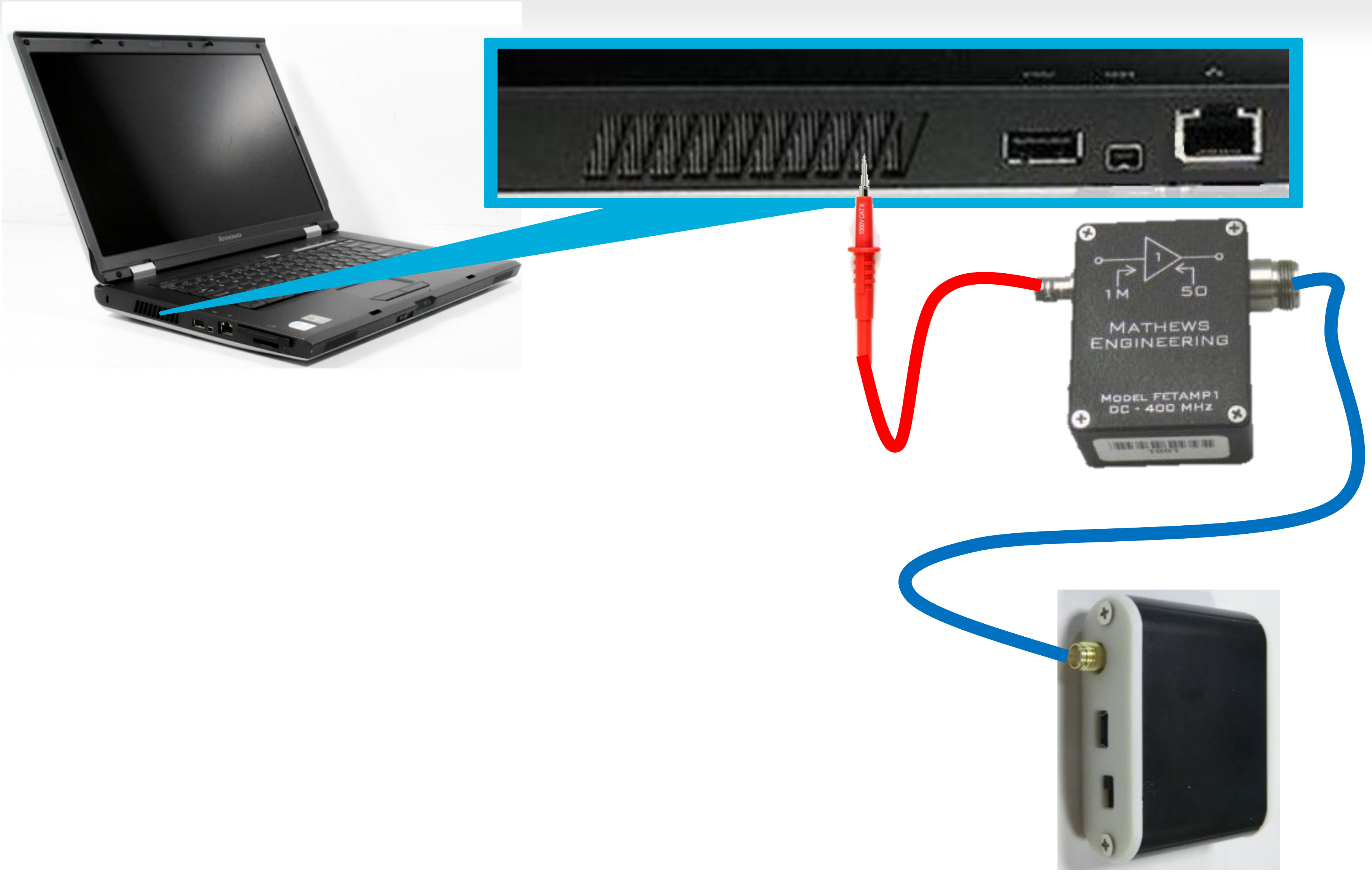

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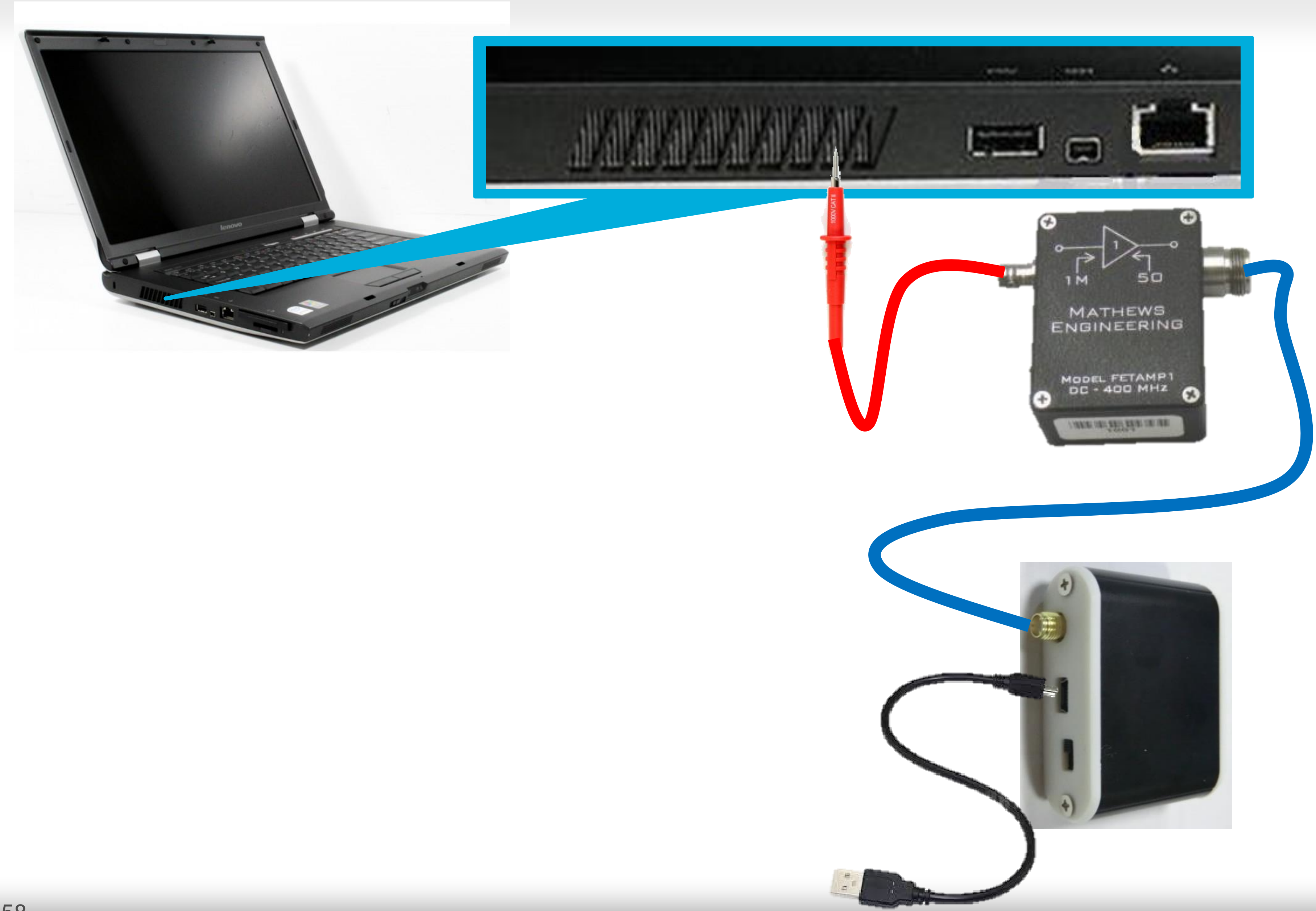

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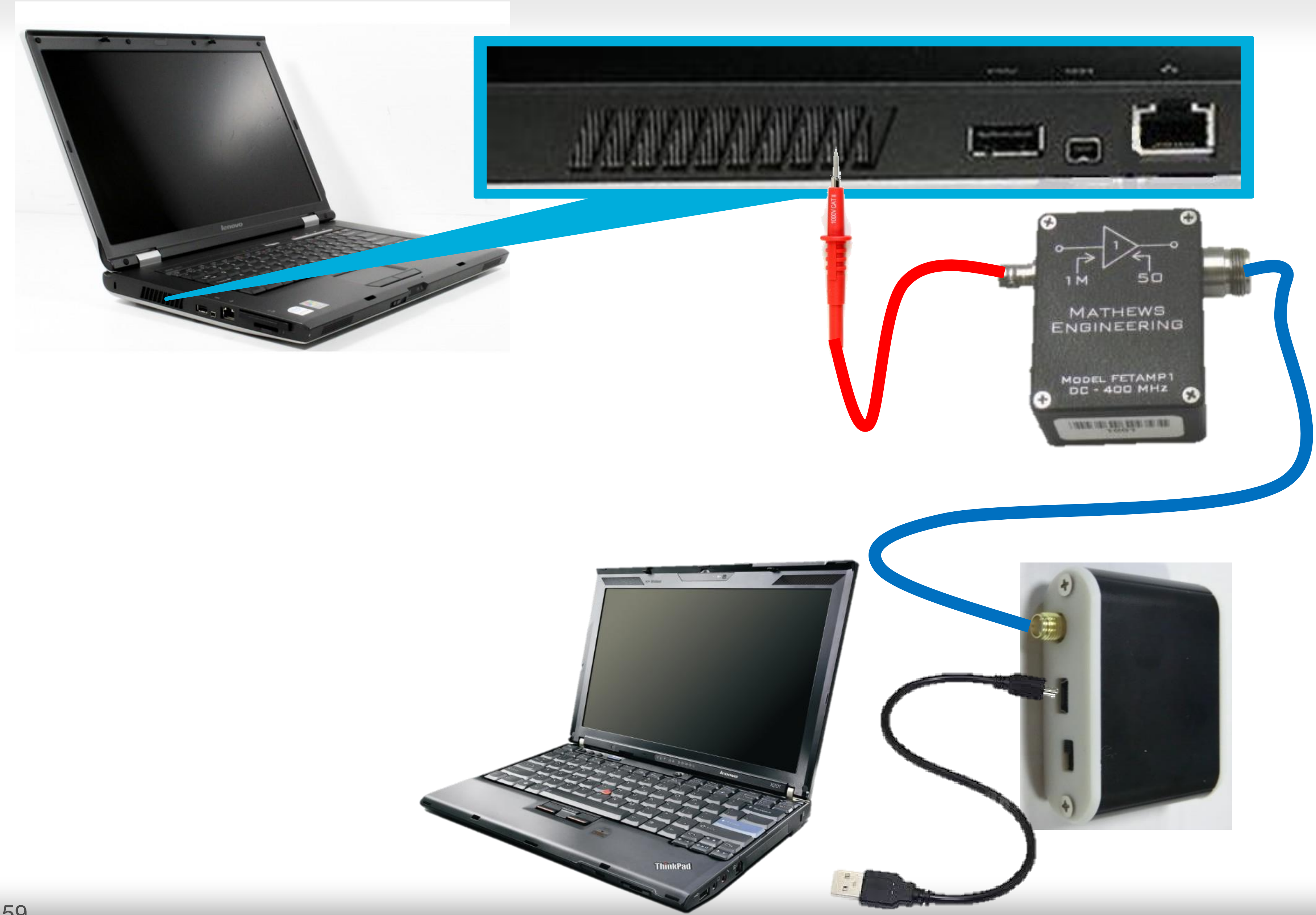

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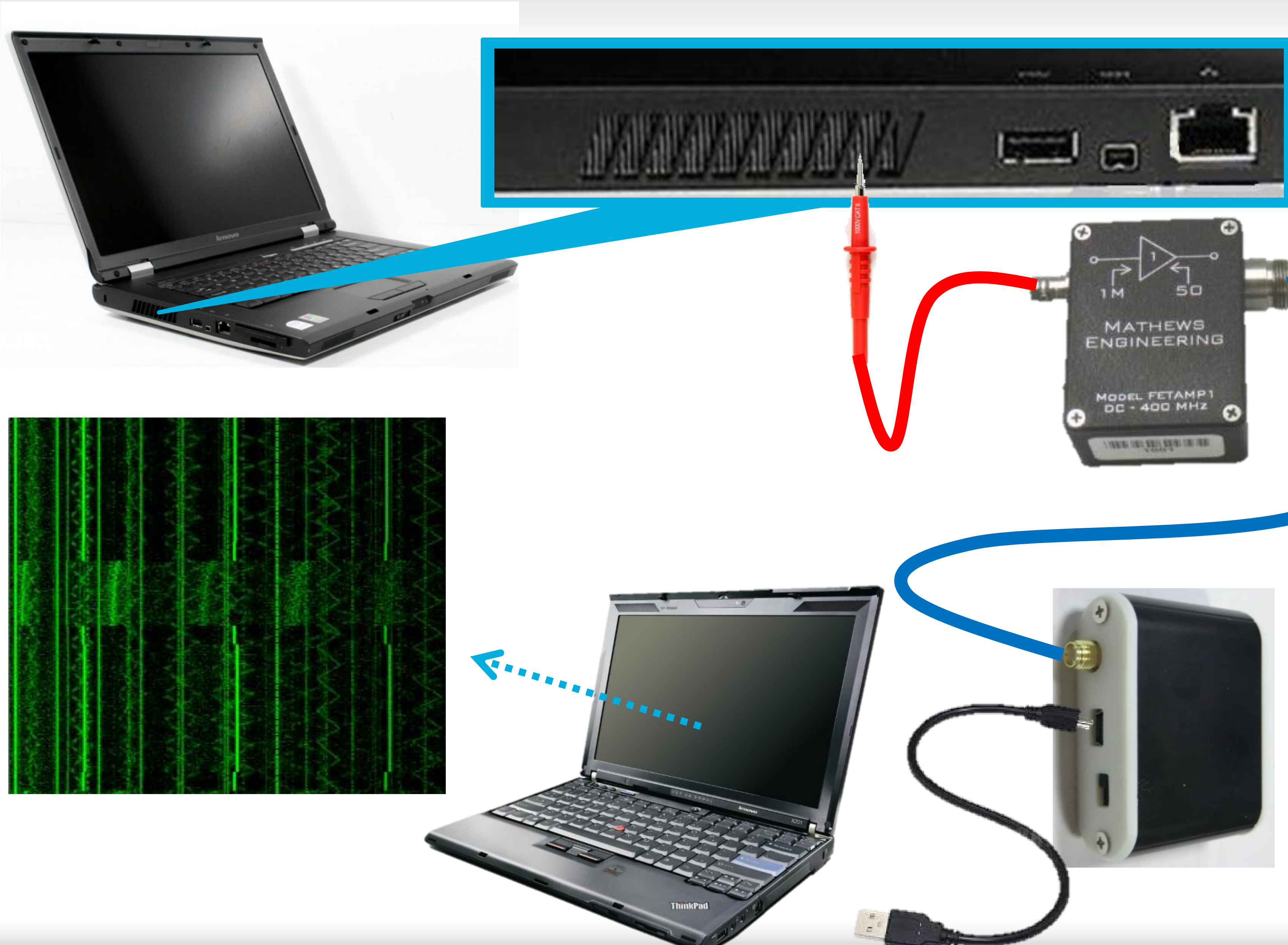
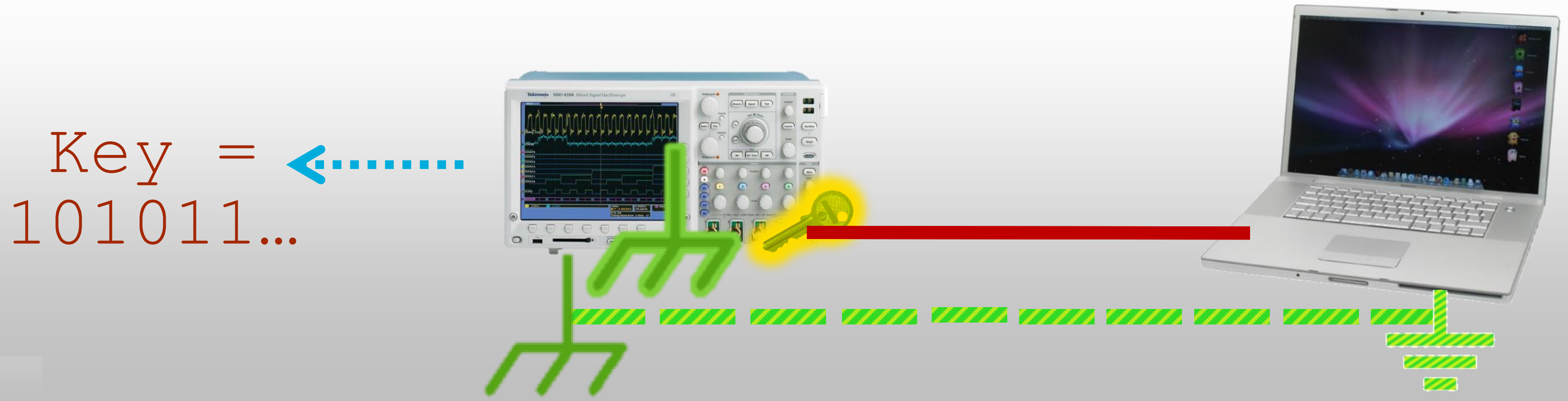
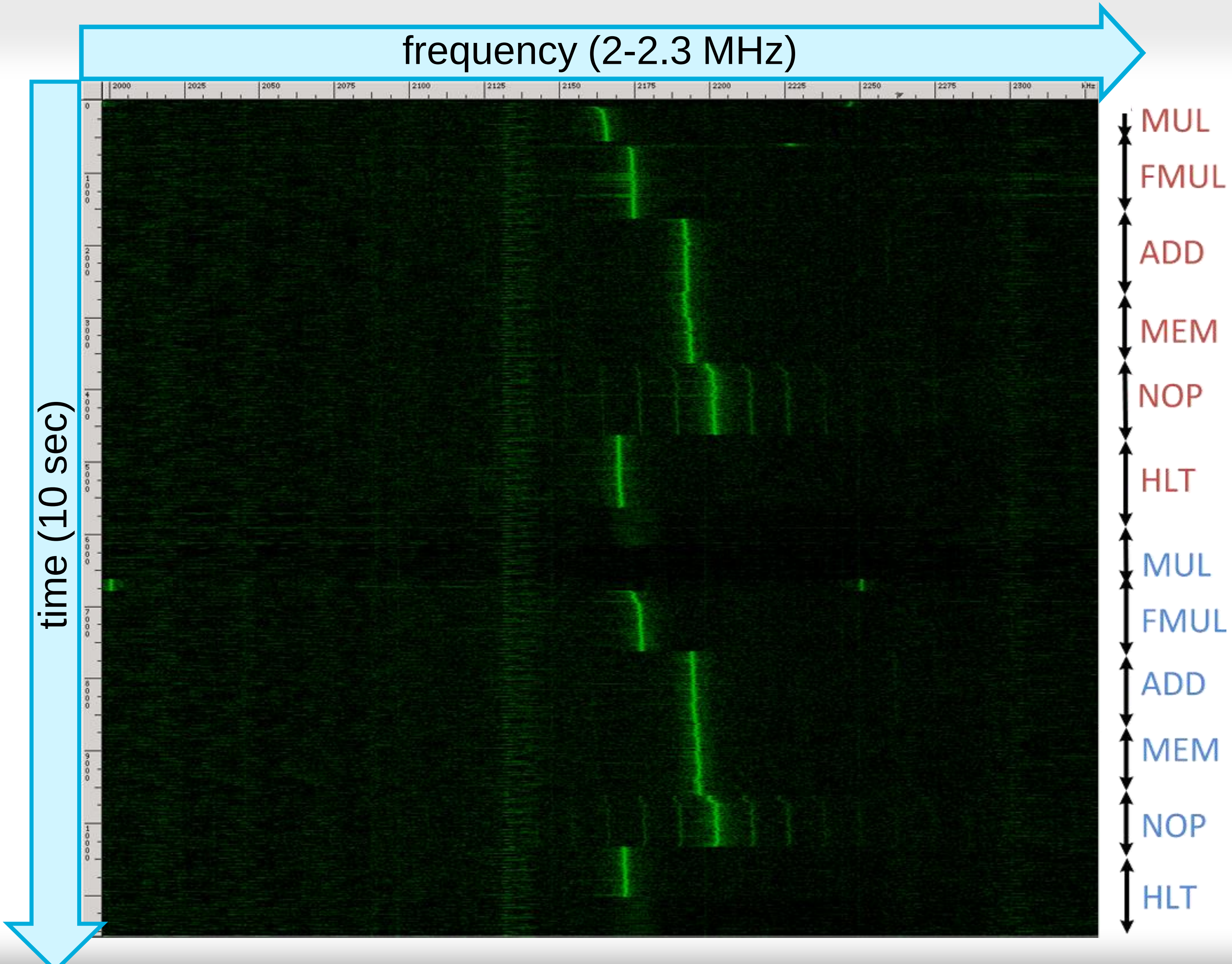


Demo:
distinguishing instructions



Distinguishing various CPU operations



Our results

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  - Ground potential (chassis and others)
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GnuPG

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Low-bandwidth leakage of RSA

Definitions (RSA)

Key setup

- **sk:** random primes p, q, private exponent d
- **pk:** $n = pq$, public exponent e

Encryption

$$c = m^e \; mod \; n$$

Decryption

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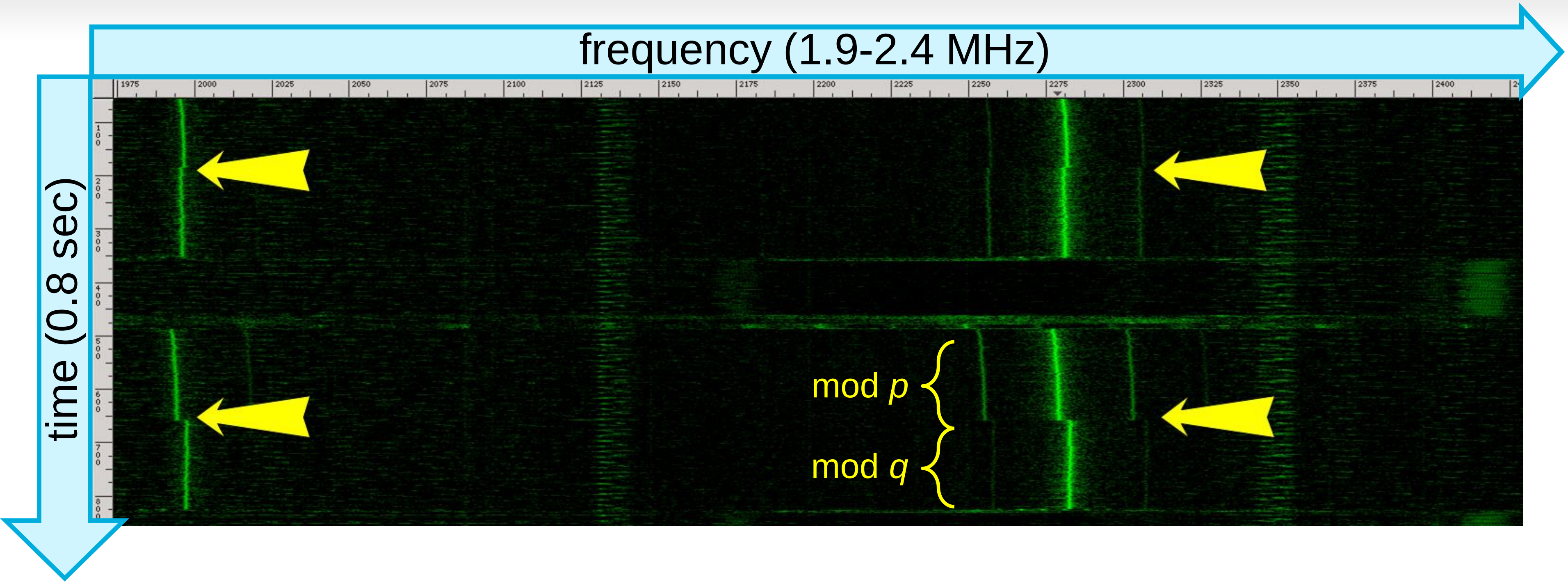
A quicker way used by most implementations

$$m_p = c^{d_p} \ mod\ p$$

$$m_q = c^{d_q} \ mod\ q$$

Obtain m using Chinese Remainder Theorem

GnuPG RSA key distinguishability



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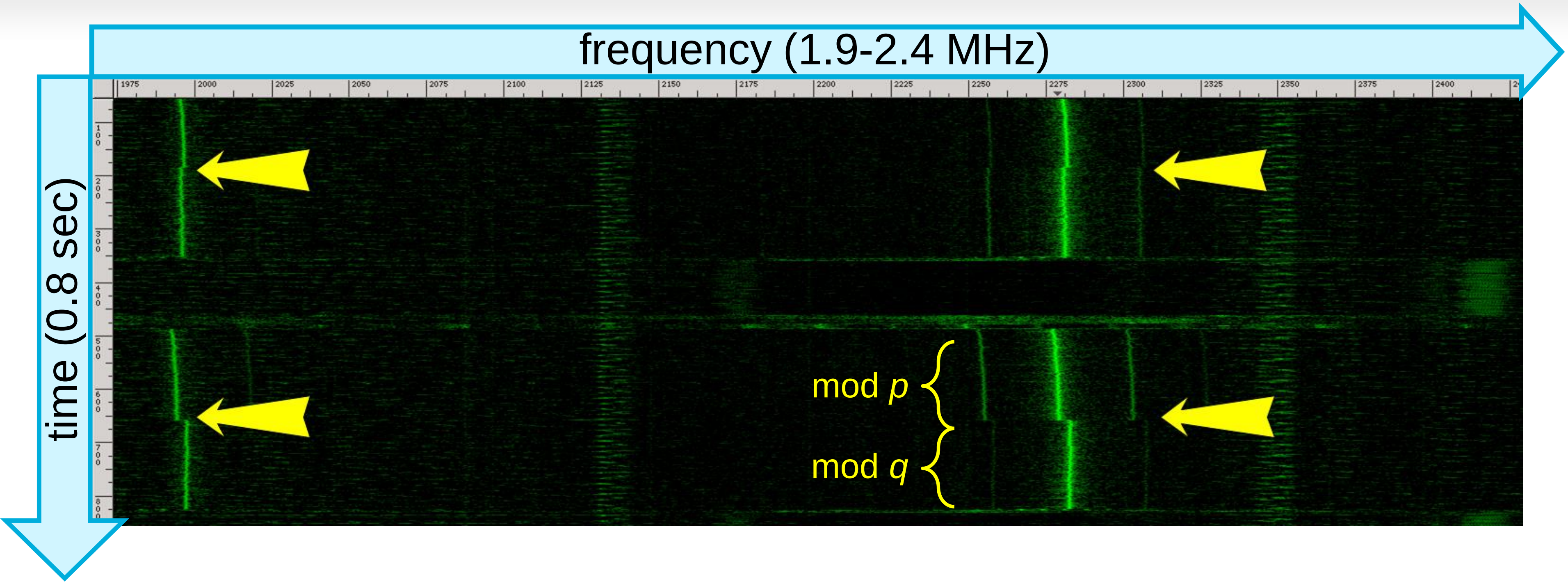
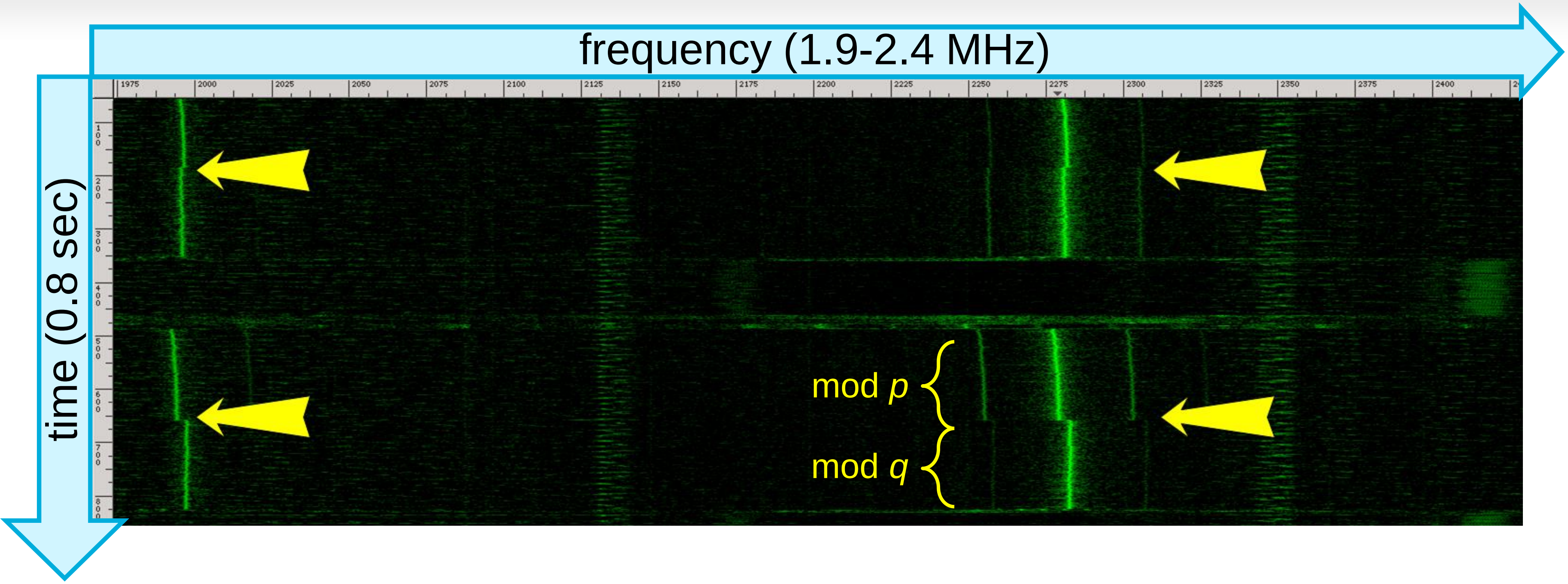


Can distinguish between:

1. Decryptions and other operations
2. Two exponentiations (mod p, mod q)

GnuPG RSA key distinguishability



Can distinguish between:

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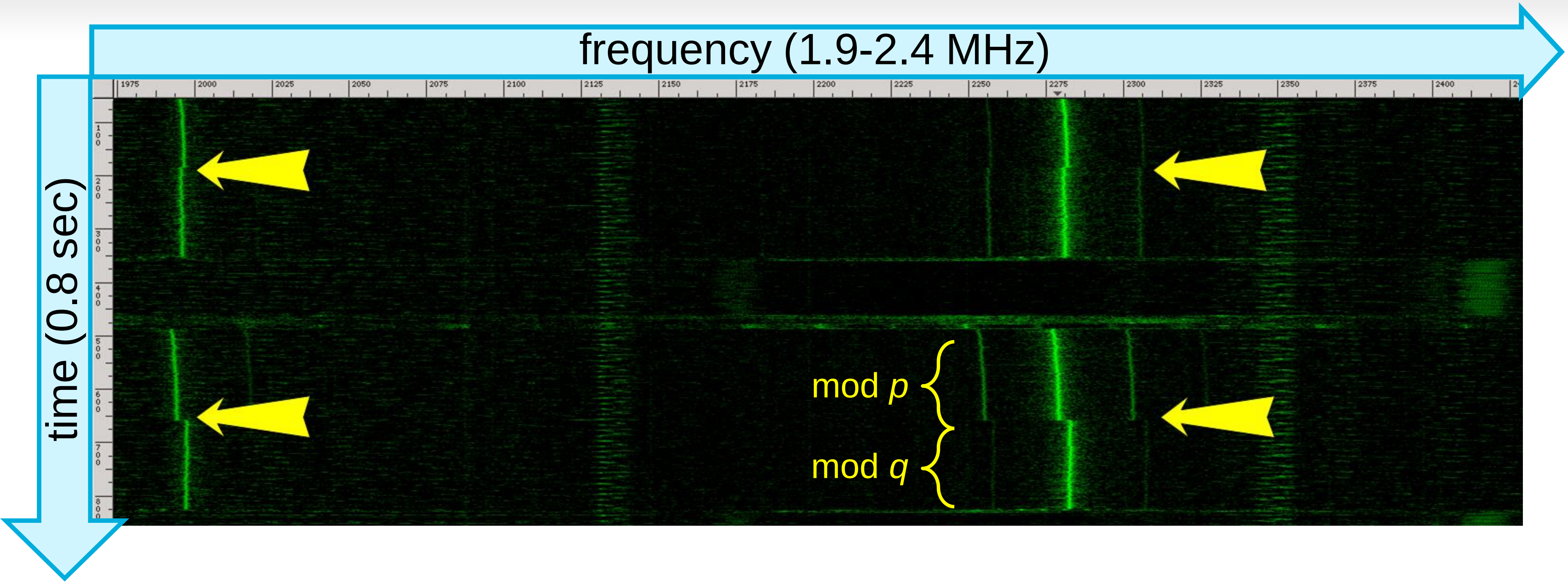

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Key extraction

GnuPG modular exponentiation

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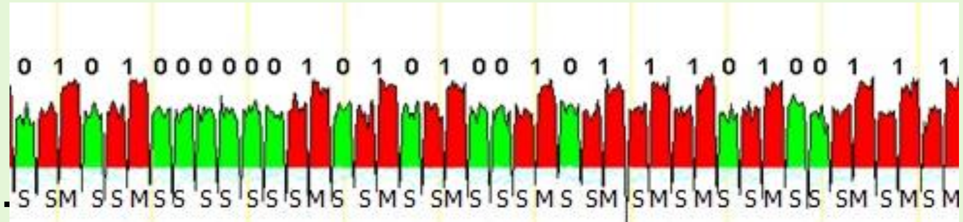

no key dependent operation to measure

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craft c such that
$d[i] = 1 \rightarrow x[j] = 0$
$d[i] = 0 \rightarrow x[j] \neq 0$
(for most j's)

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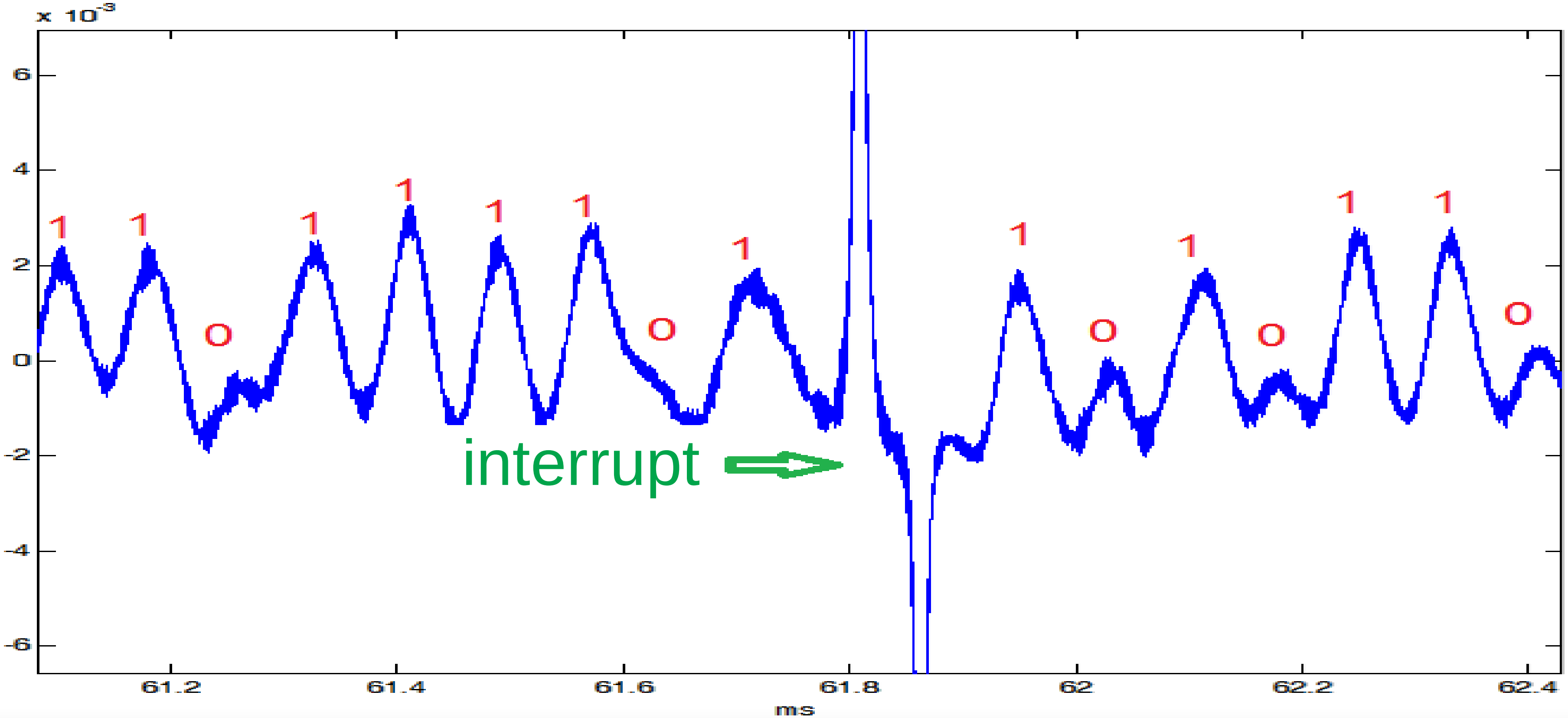
- Send chosen ciphertexts using Enigmail

Empirical results

Reading the secret key (non-adaptive attack)

- Acquire trace
- Filter around carrier (1.7 MHz)
- FM demodulation
- Read out bits ("simple ground analysis")



Demo:
key extraction

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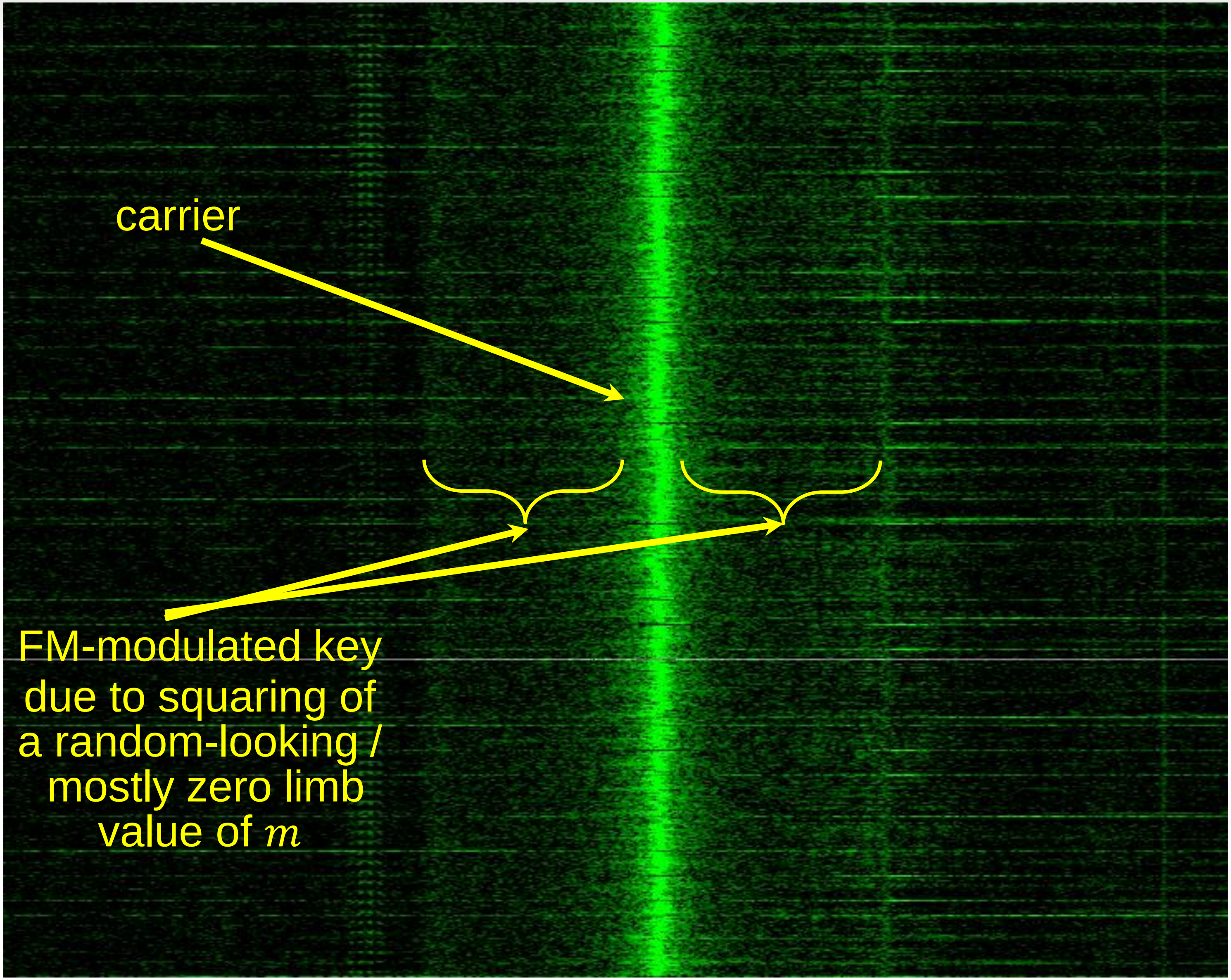
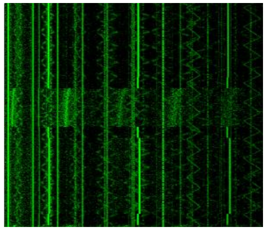
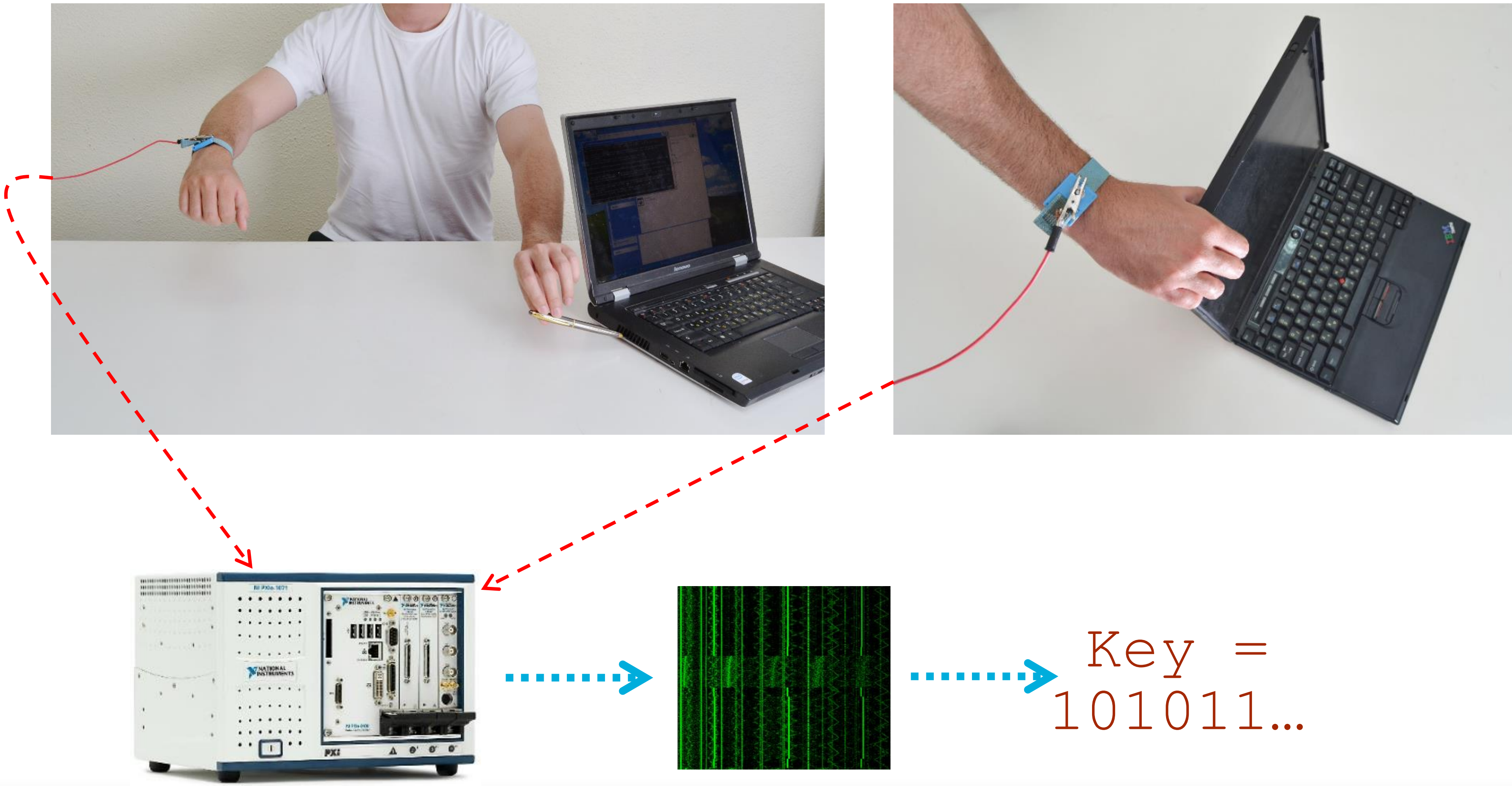


RSA and ElGamal key extraction in a few seconds using direct chassis measurement (non-adaptive attack)



Key = 101011…

RSA and ElGamal key extraction in a few seconds using human touch (non-adaptive attack)



Ground-potential analysis

- **Attenuating EMI emanations**
  "Unwanted currents or electromagnetic fields? Dump them to the circuit ground!"
  (Bypass capacitors, RF shields, …)

- Device is grounded, but its "ground" potential fluctuates relative to the mains earth ground.

	Computation
affects	currents and EM fields
dumped to	device ground
connected to	conductive chassis

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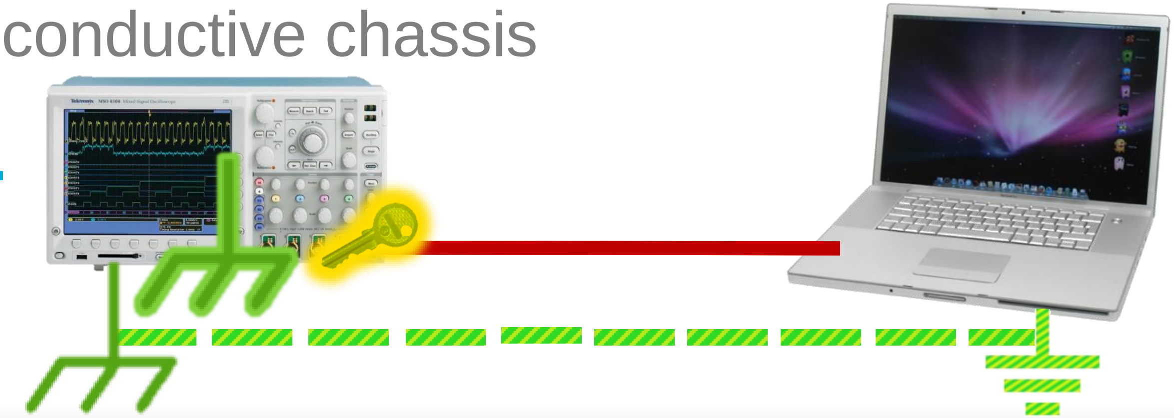

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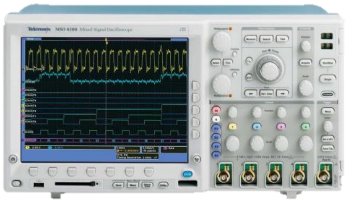

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Even when no data, or port is turned off.

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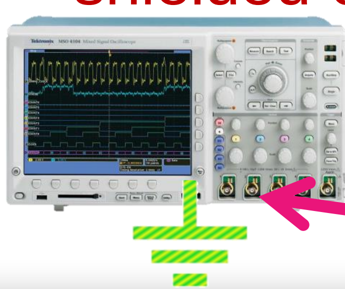

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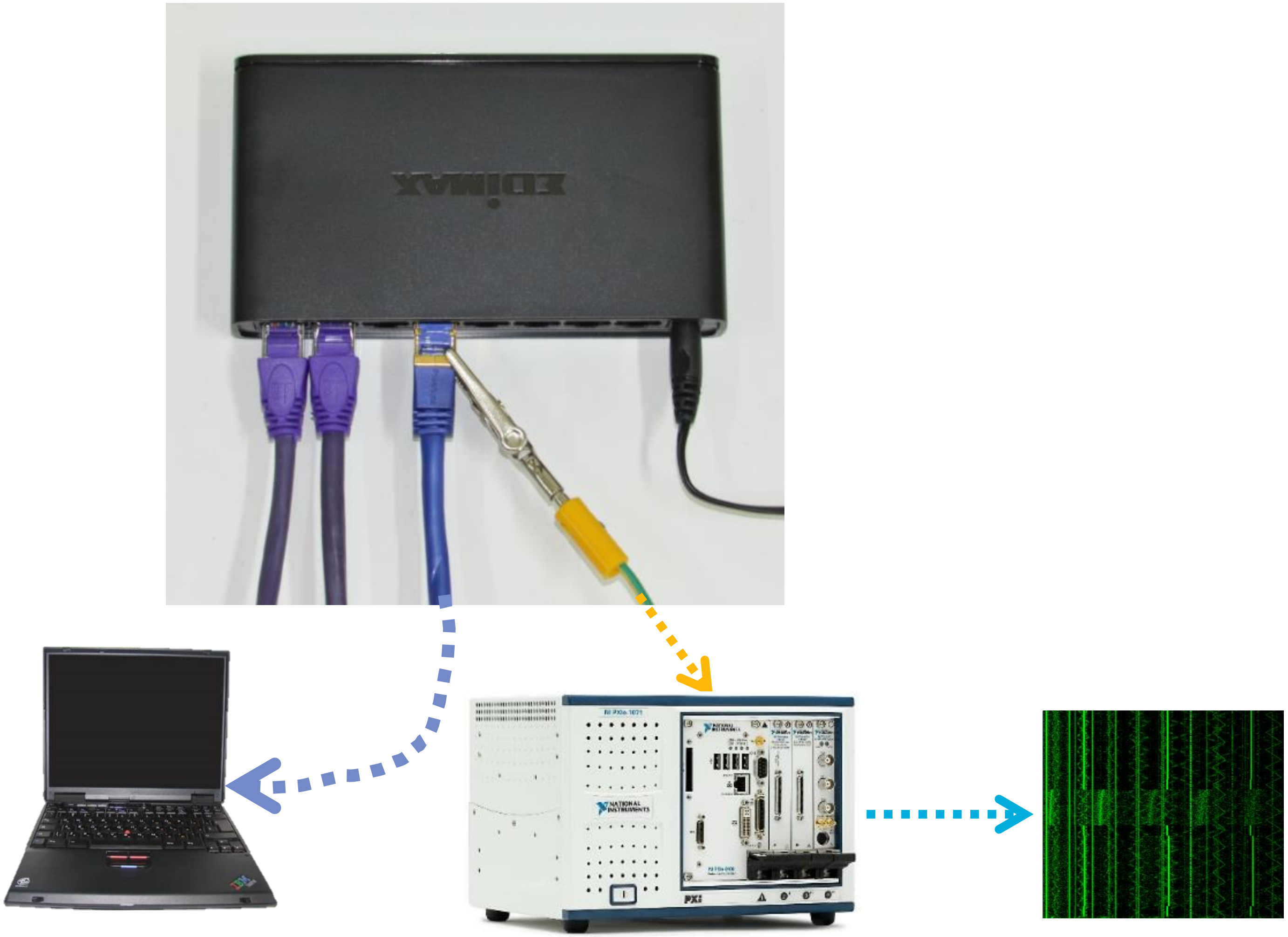
RSA and ElGamal key extraction in a few seconds using the far end of 10 meter network cable (non-adaptive attack)



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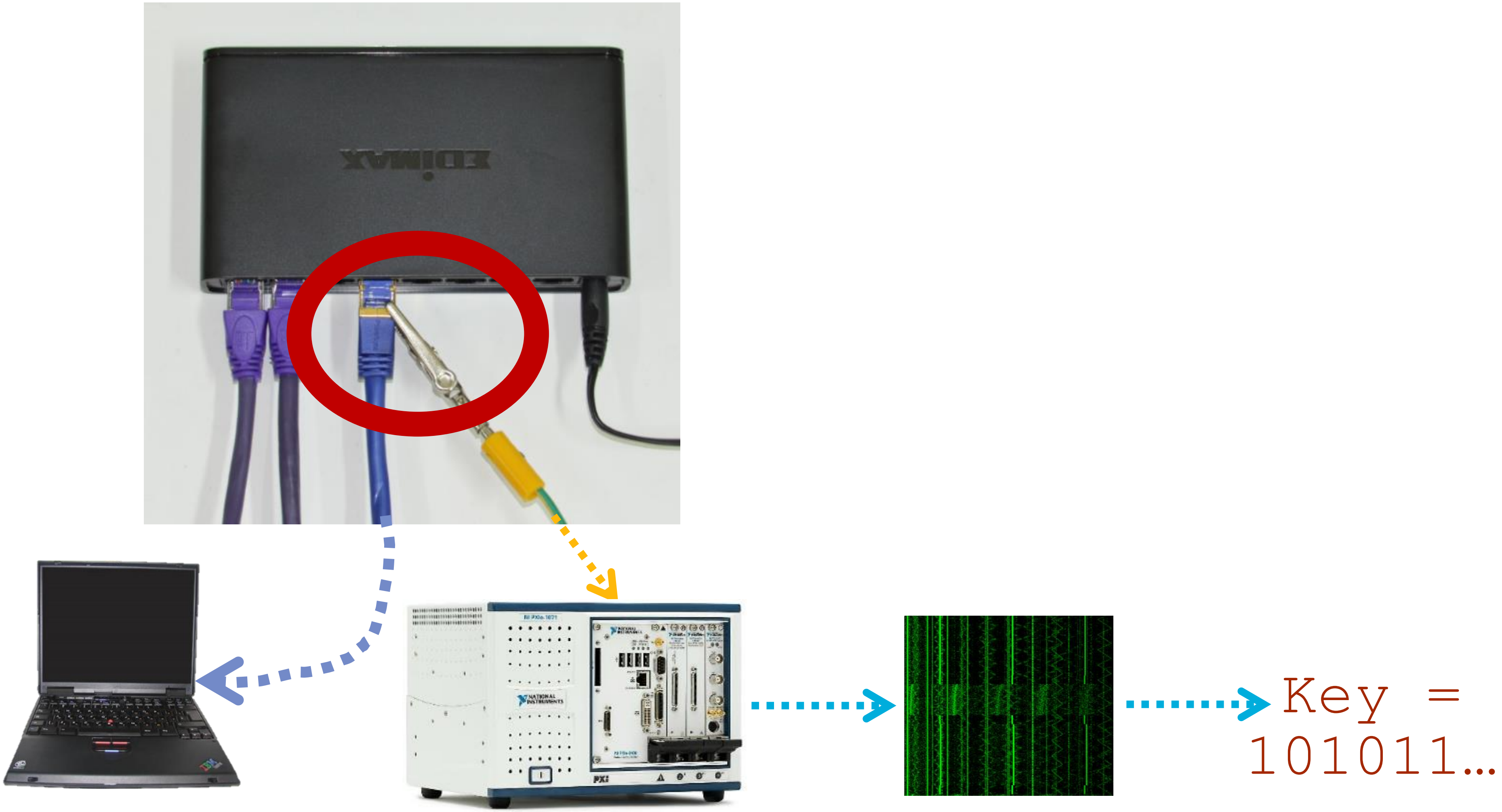
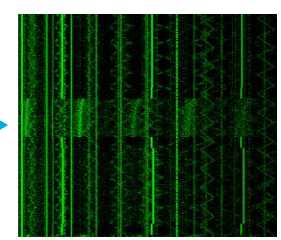


RSA and ElGamal key extraction in a few seconds using the far end of 10 meter network cable (non-adaptive attack)

works even if a firewall is present, or port is turned off



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Key extraction on far side of Ethernet cable using a mobile phone

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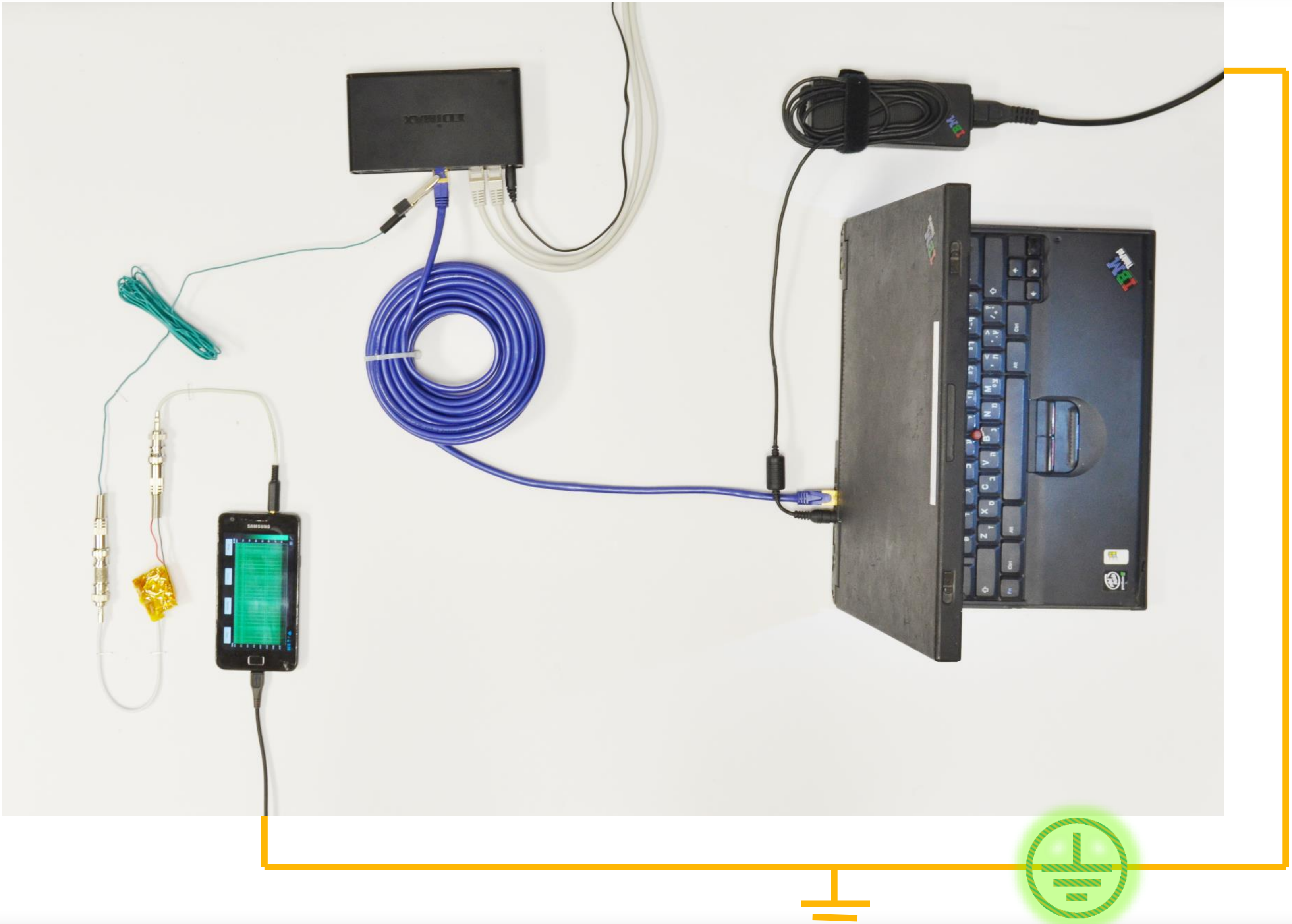

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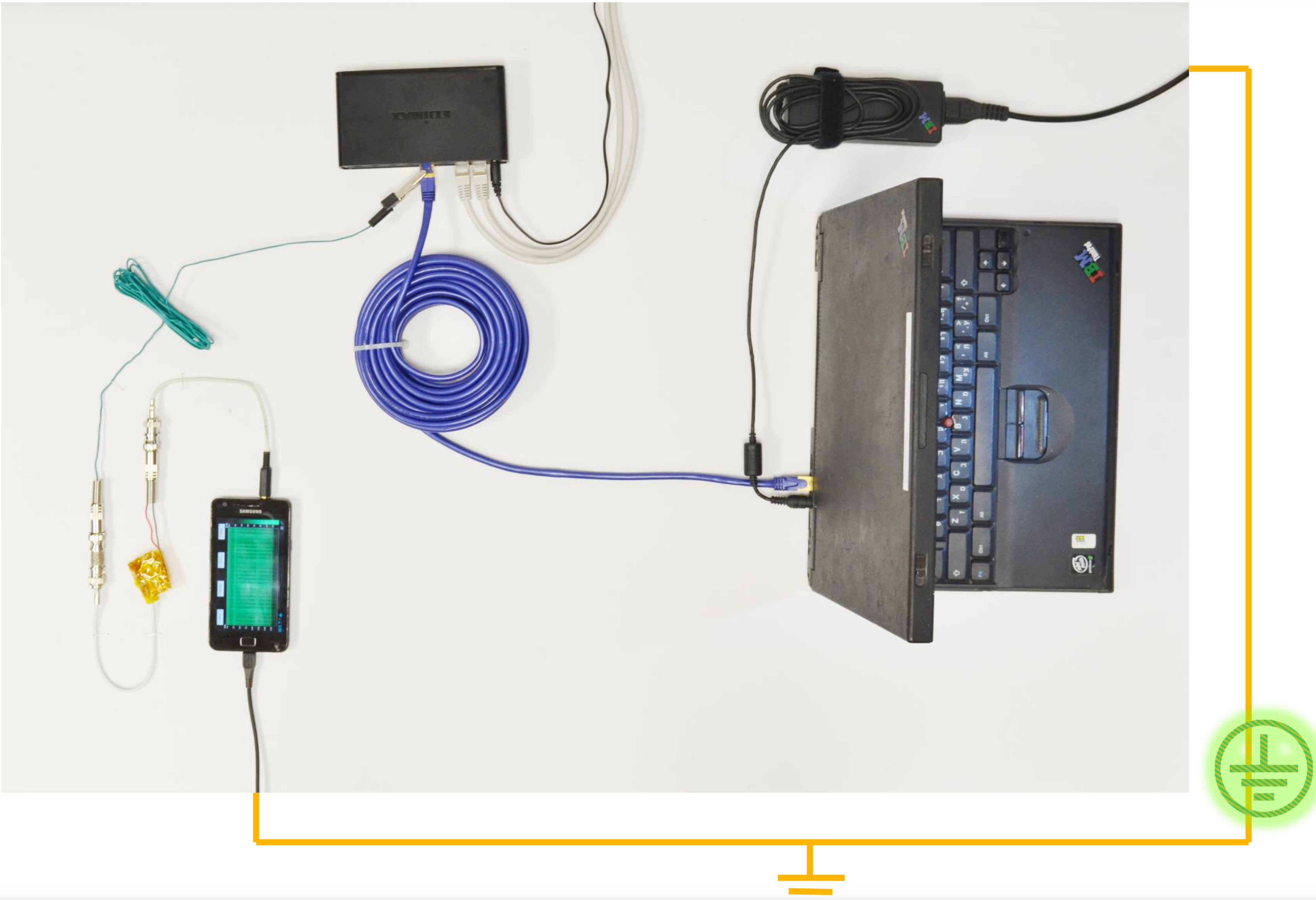

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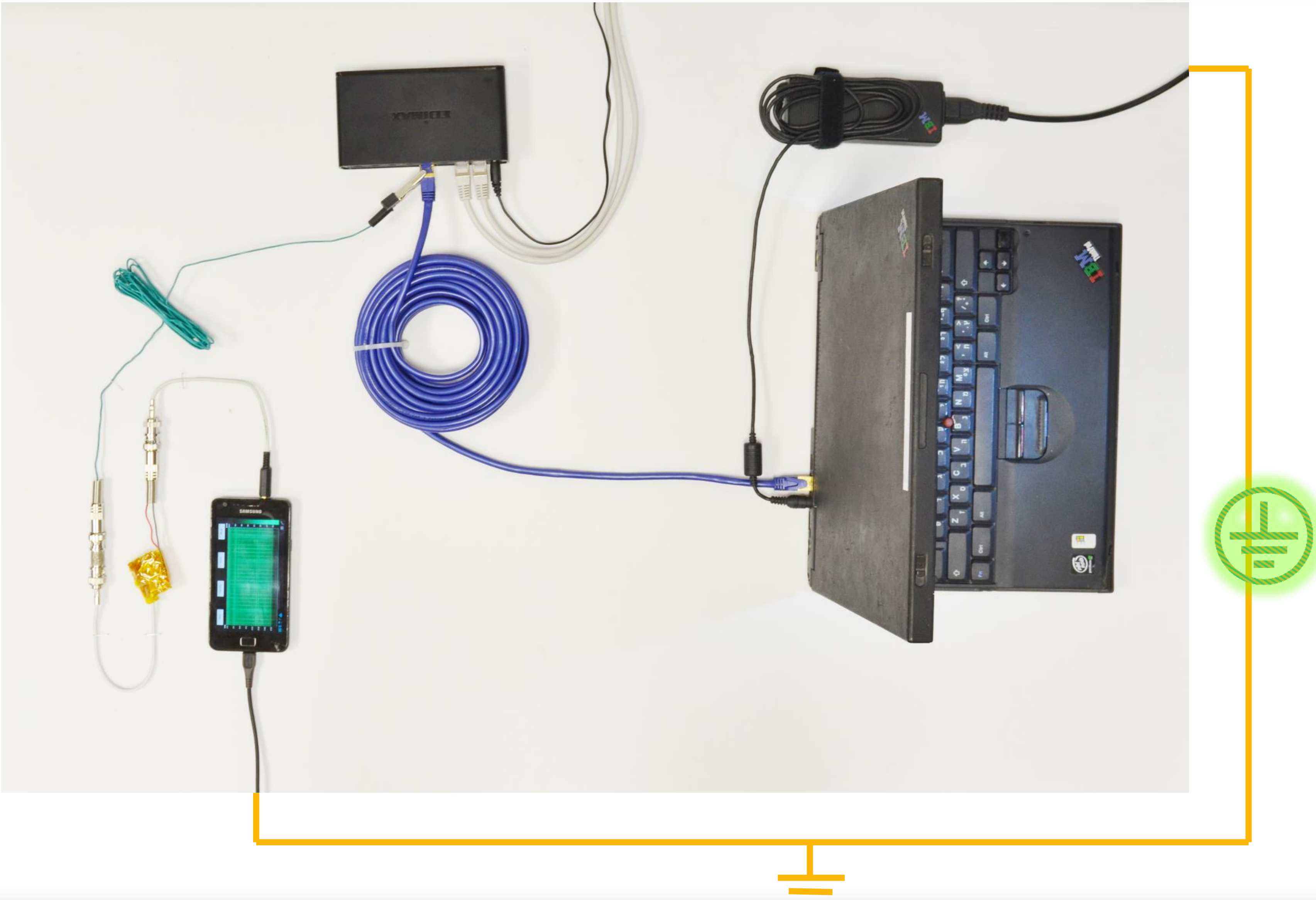

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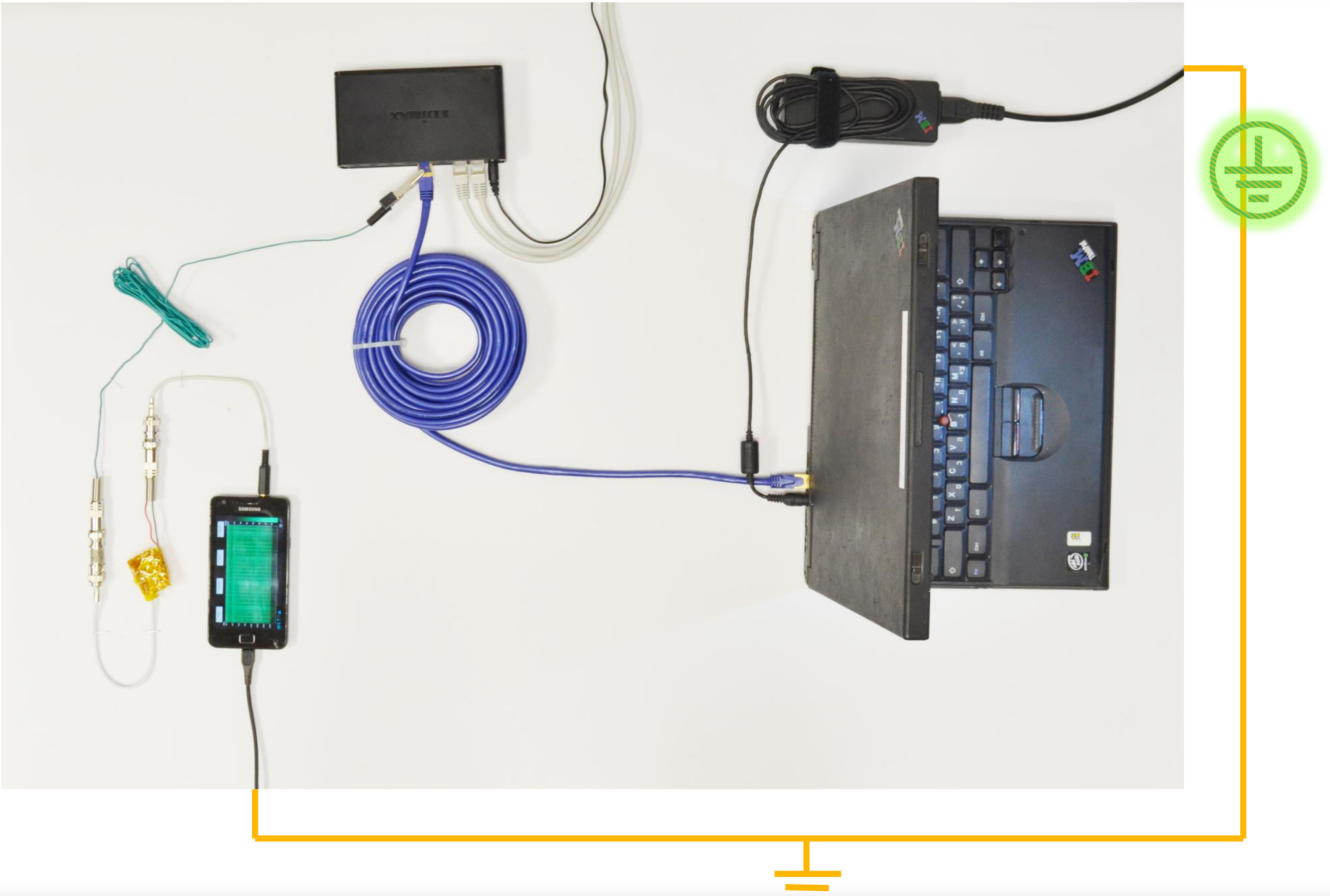

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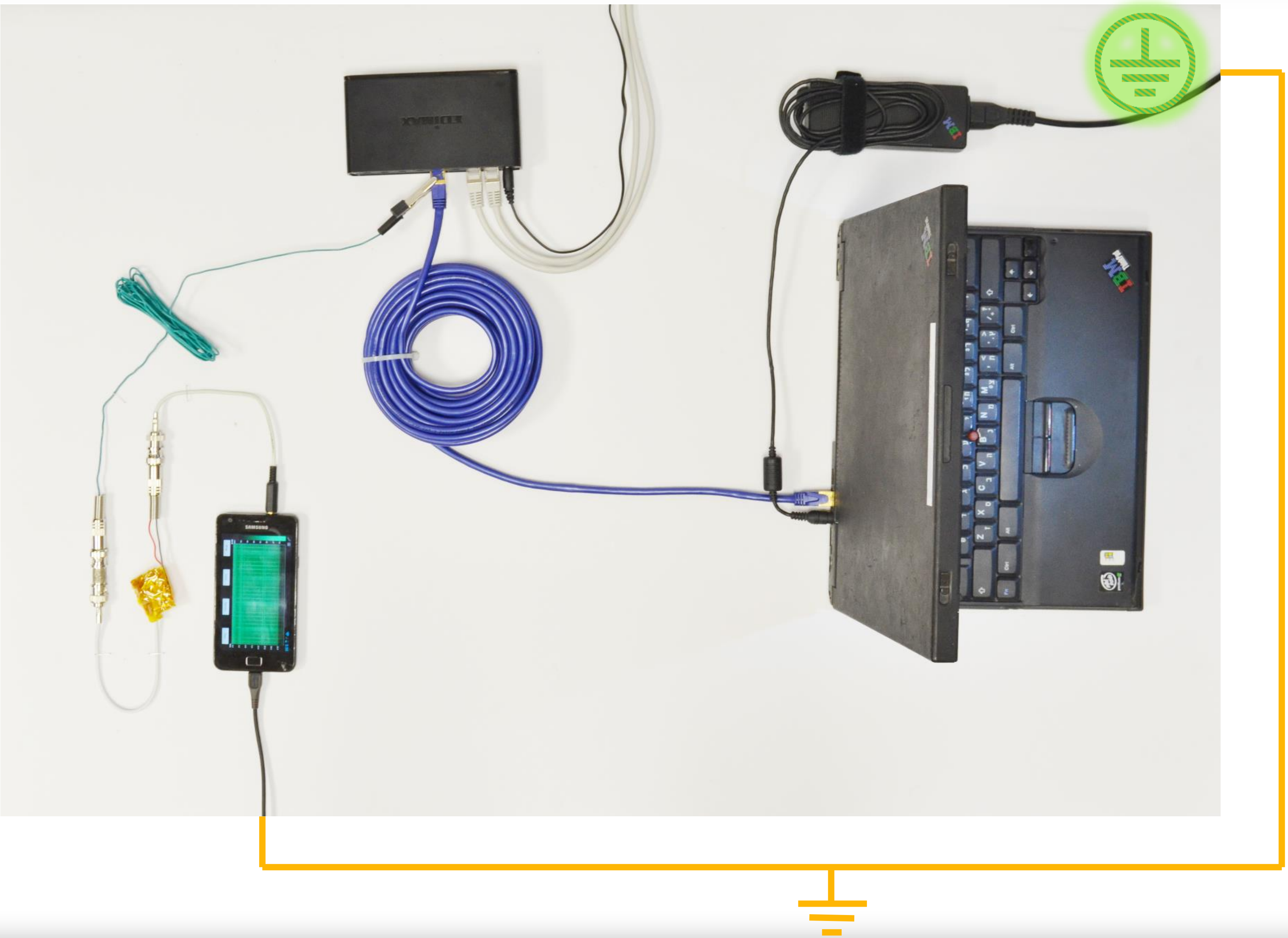

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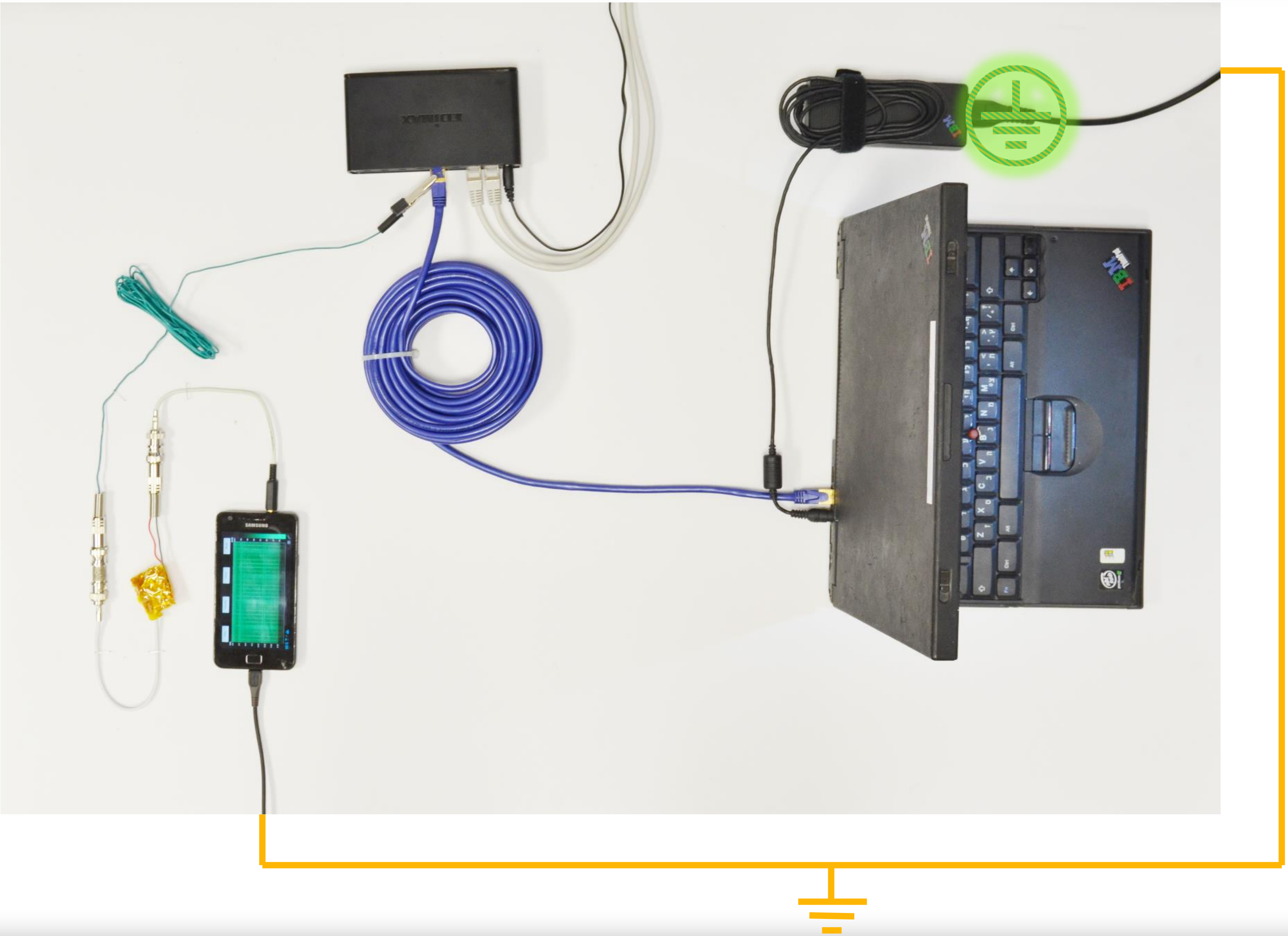

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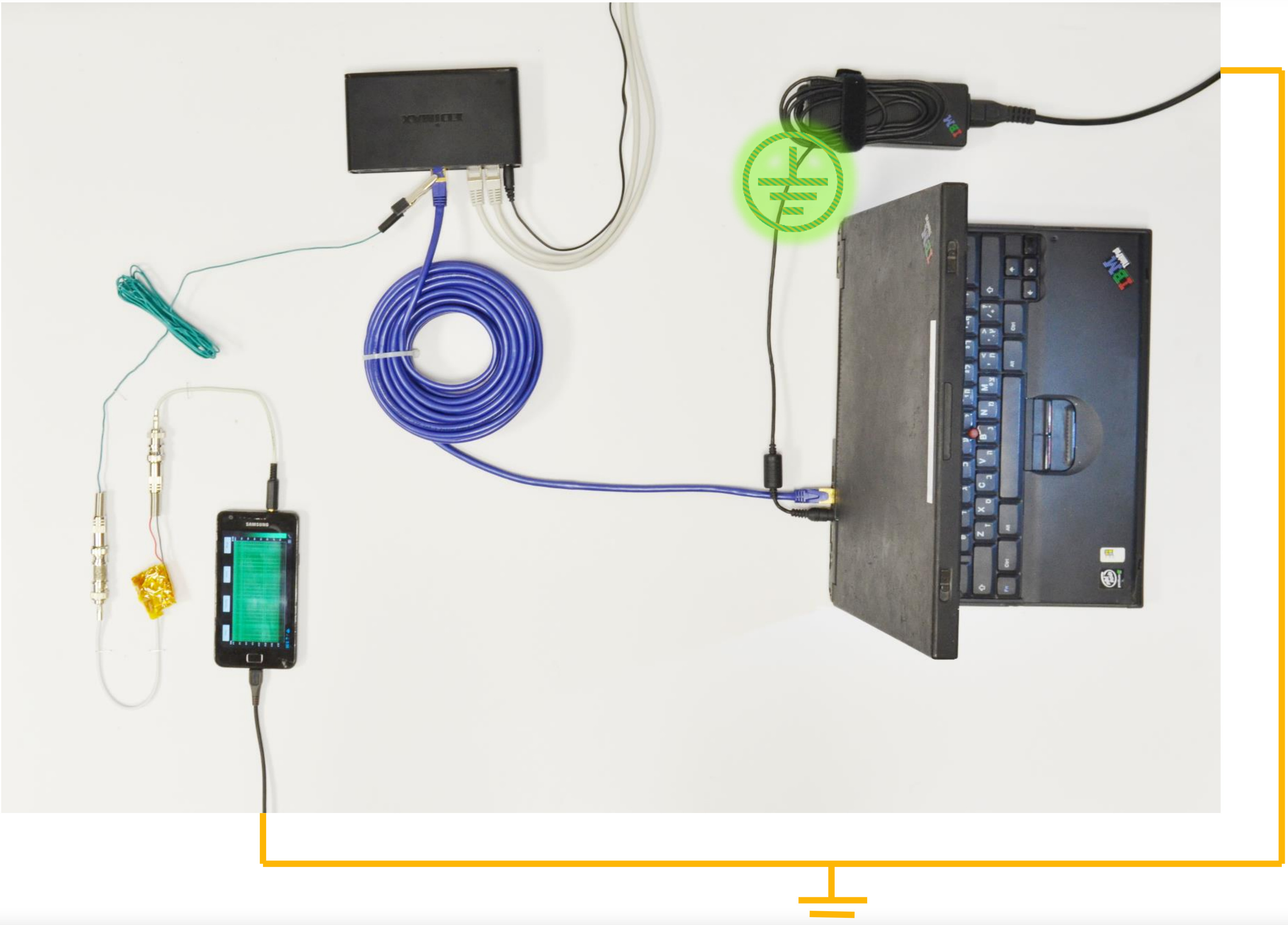

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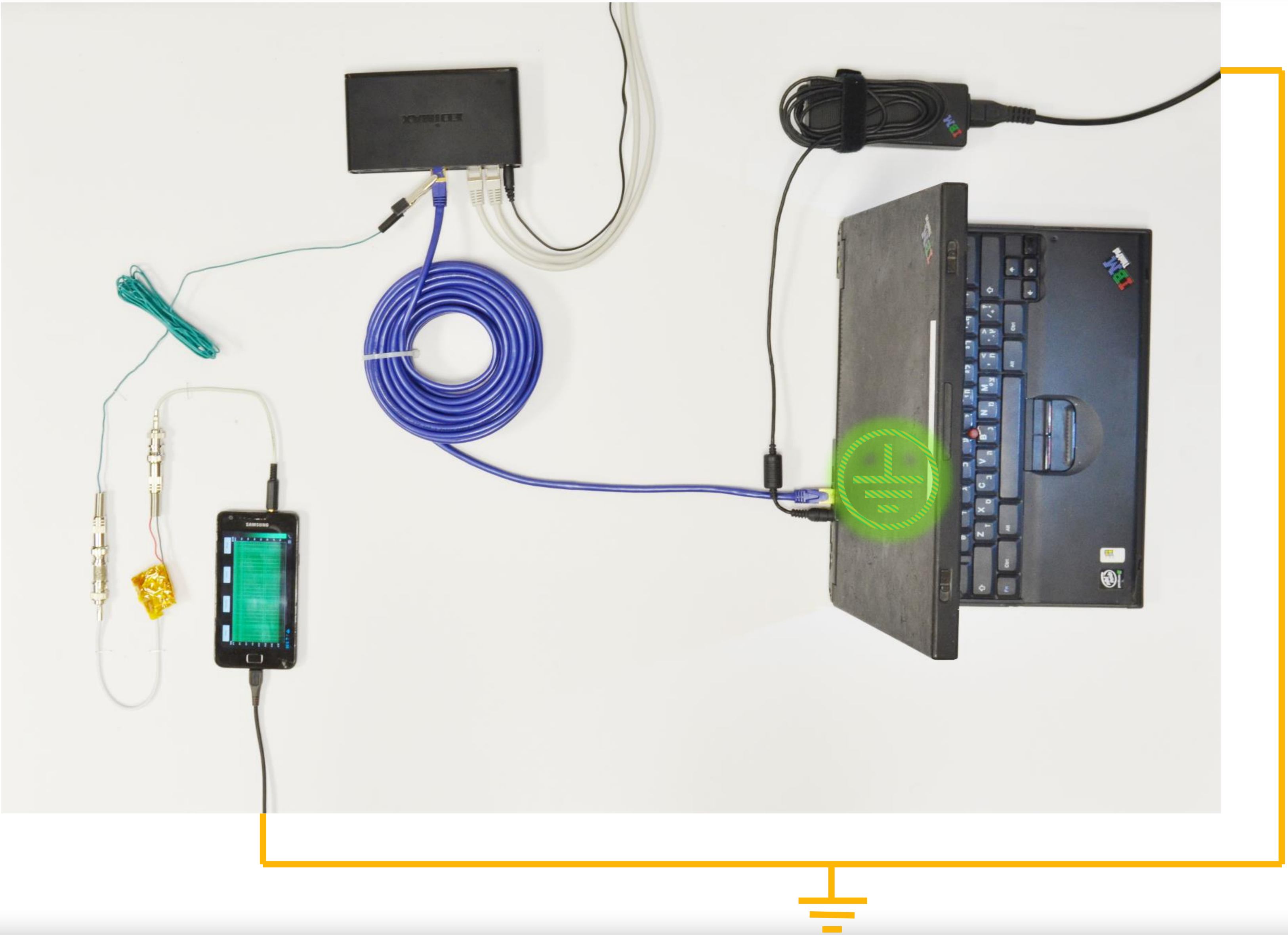

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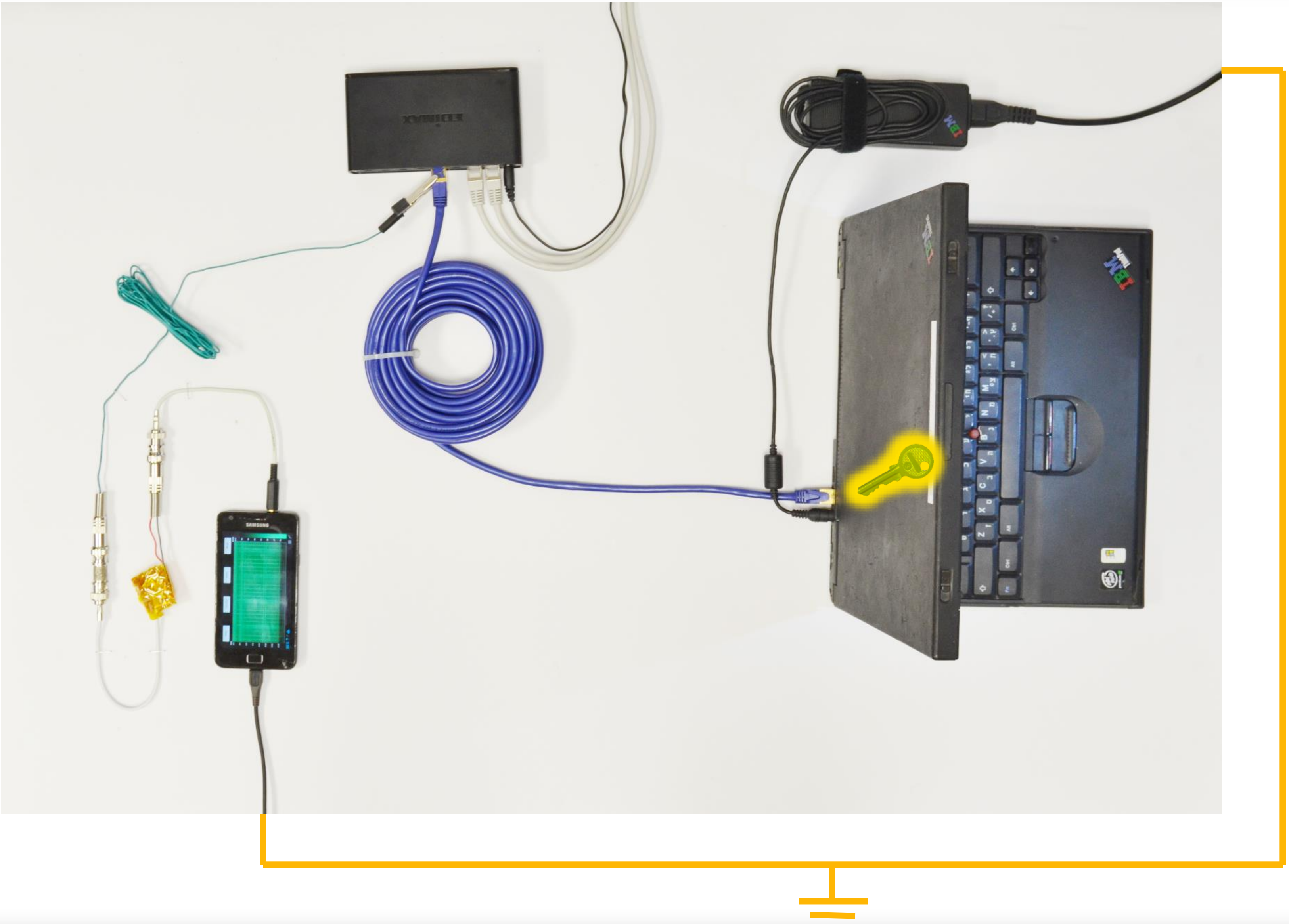

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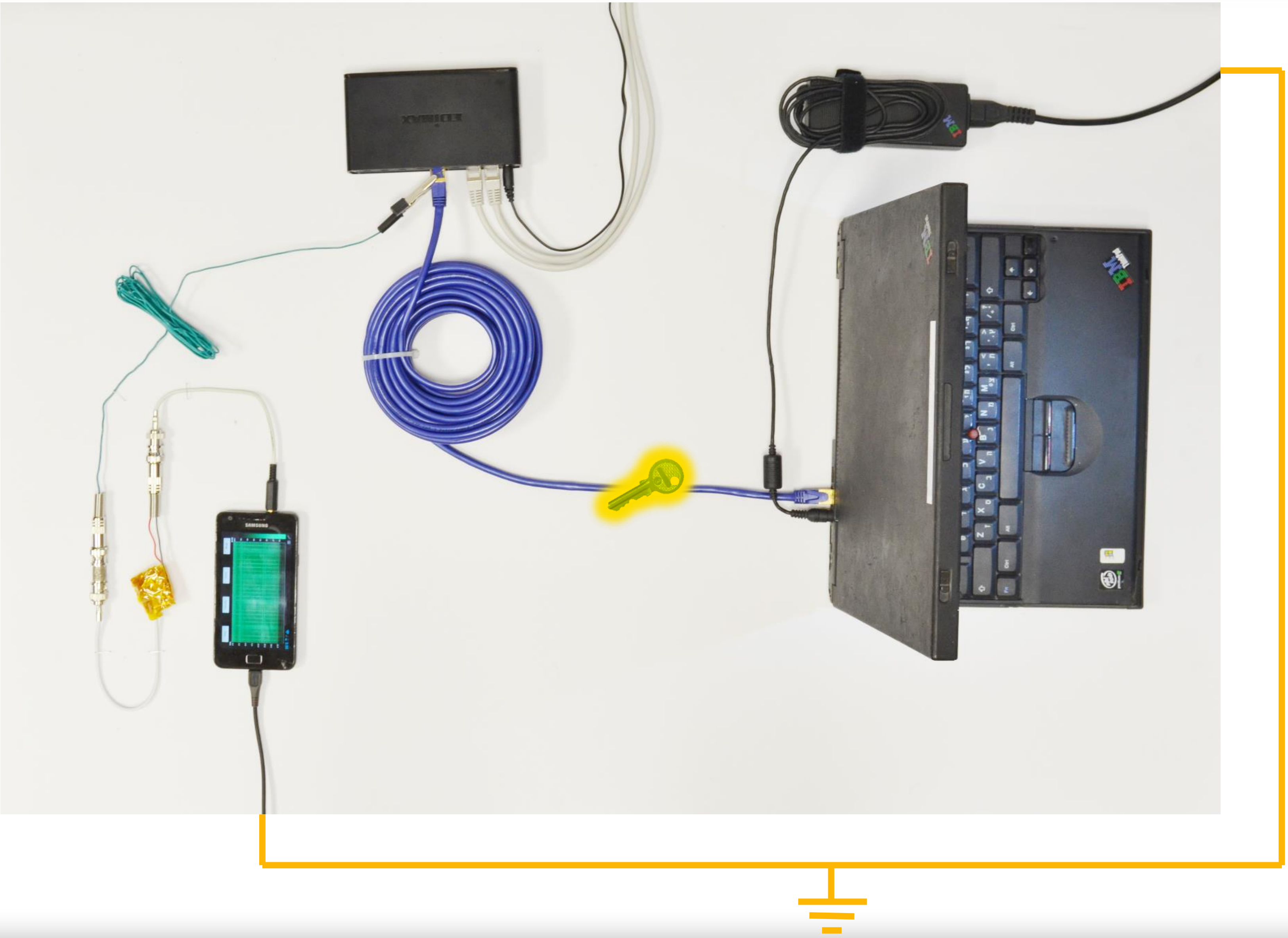

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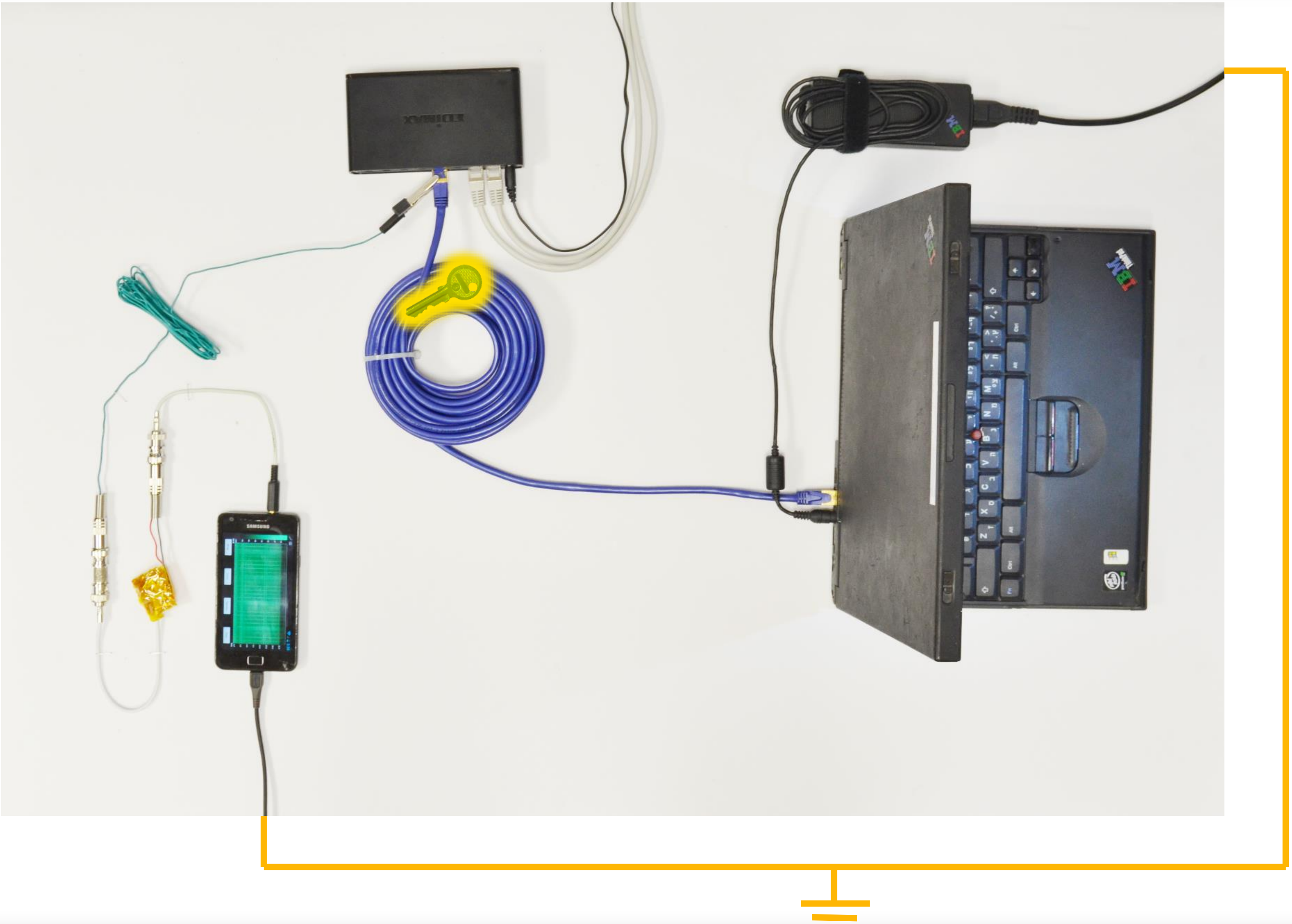

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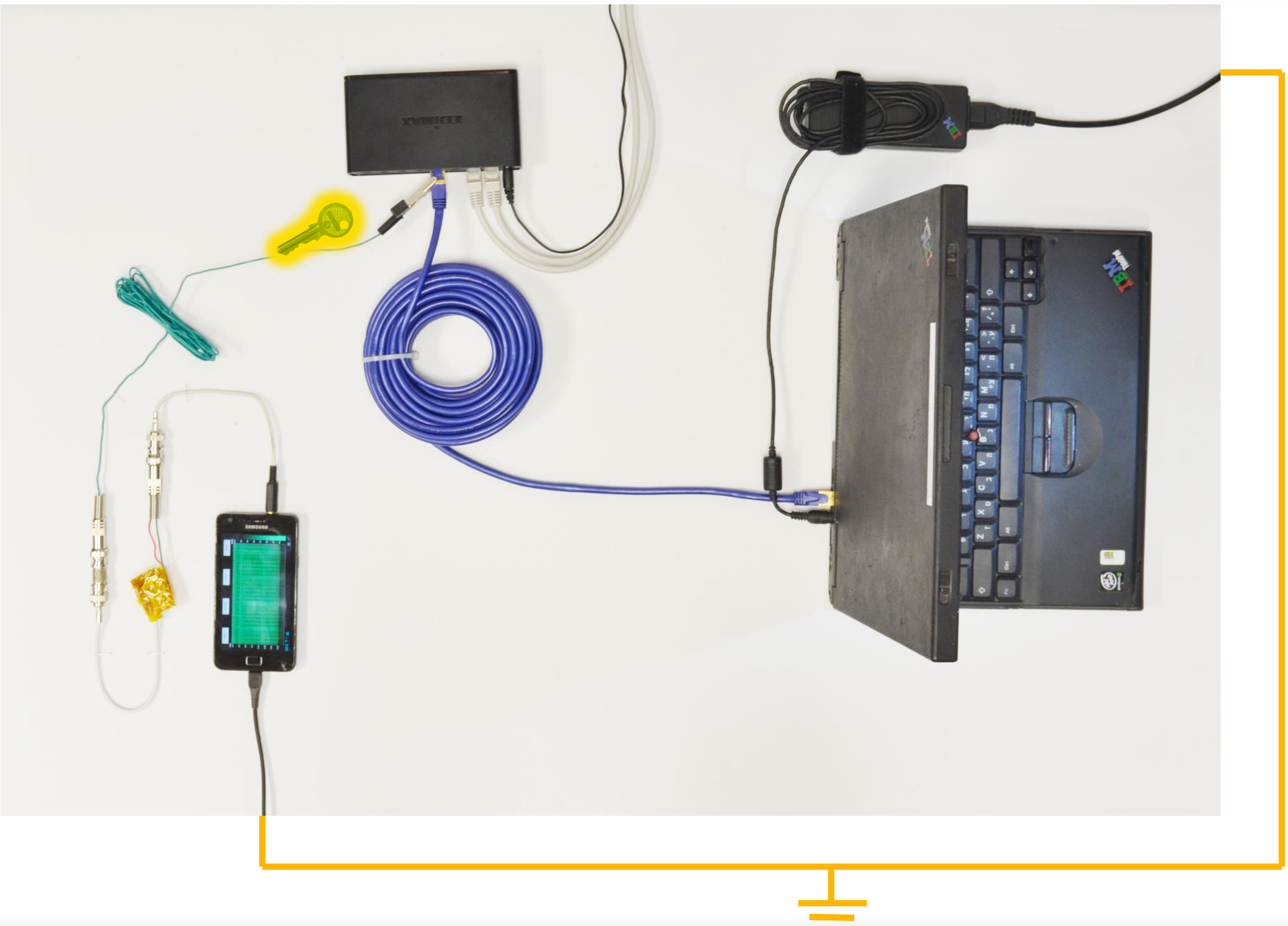

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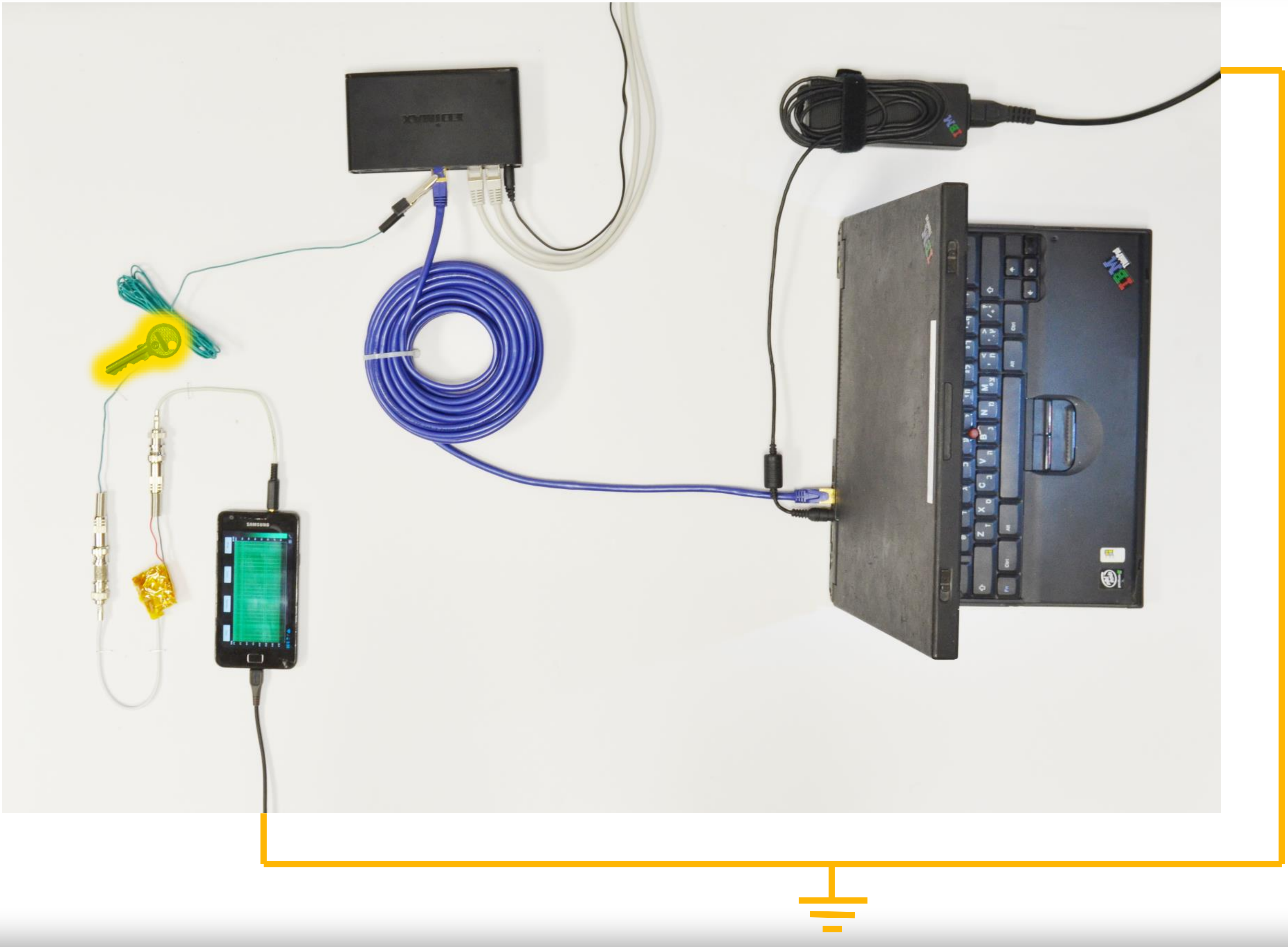

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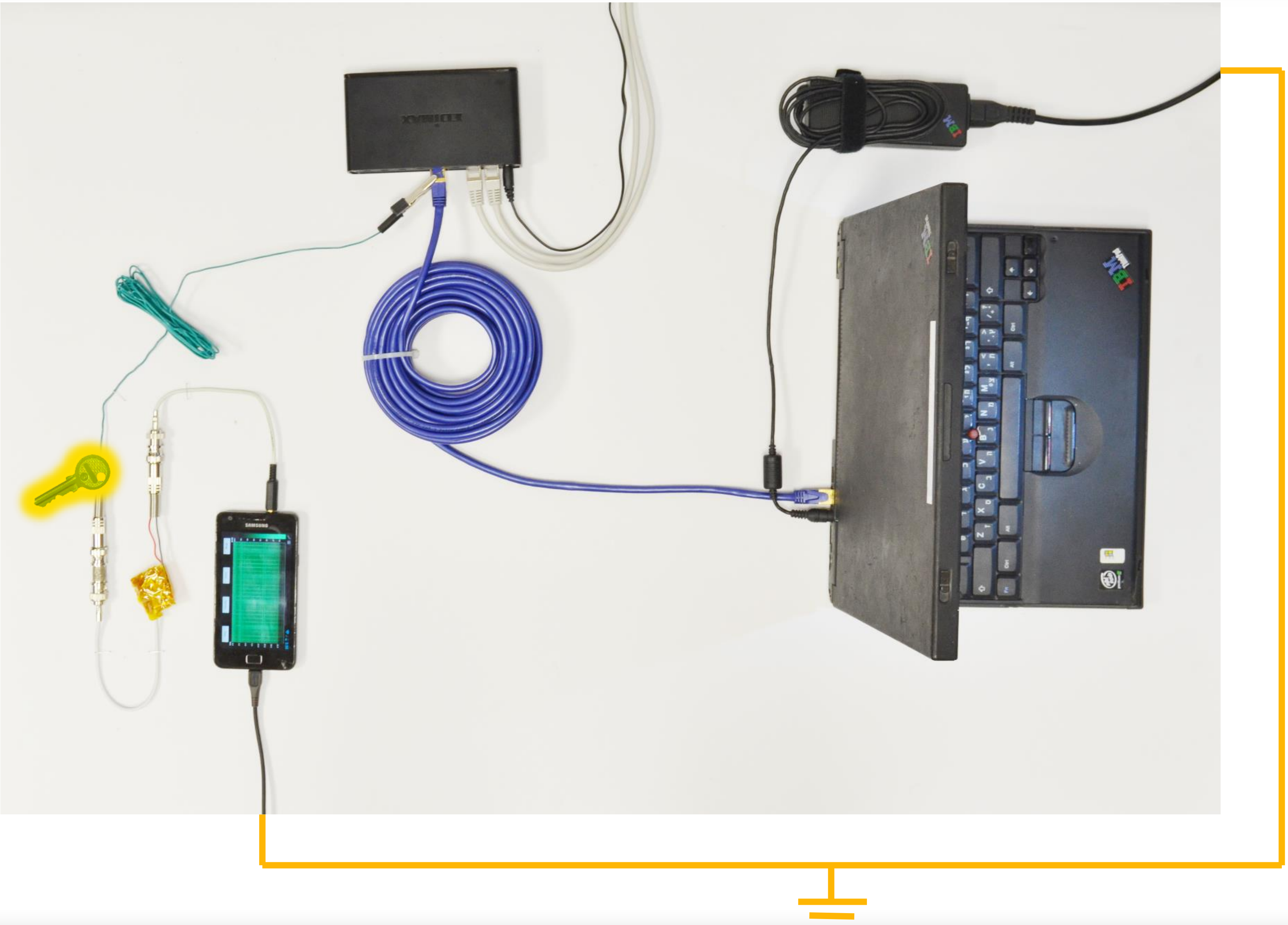

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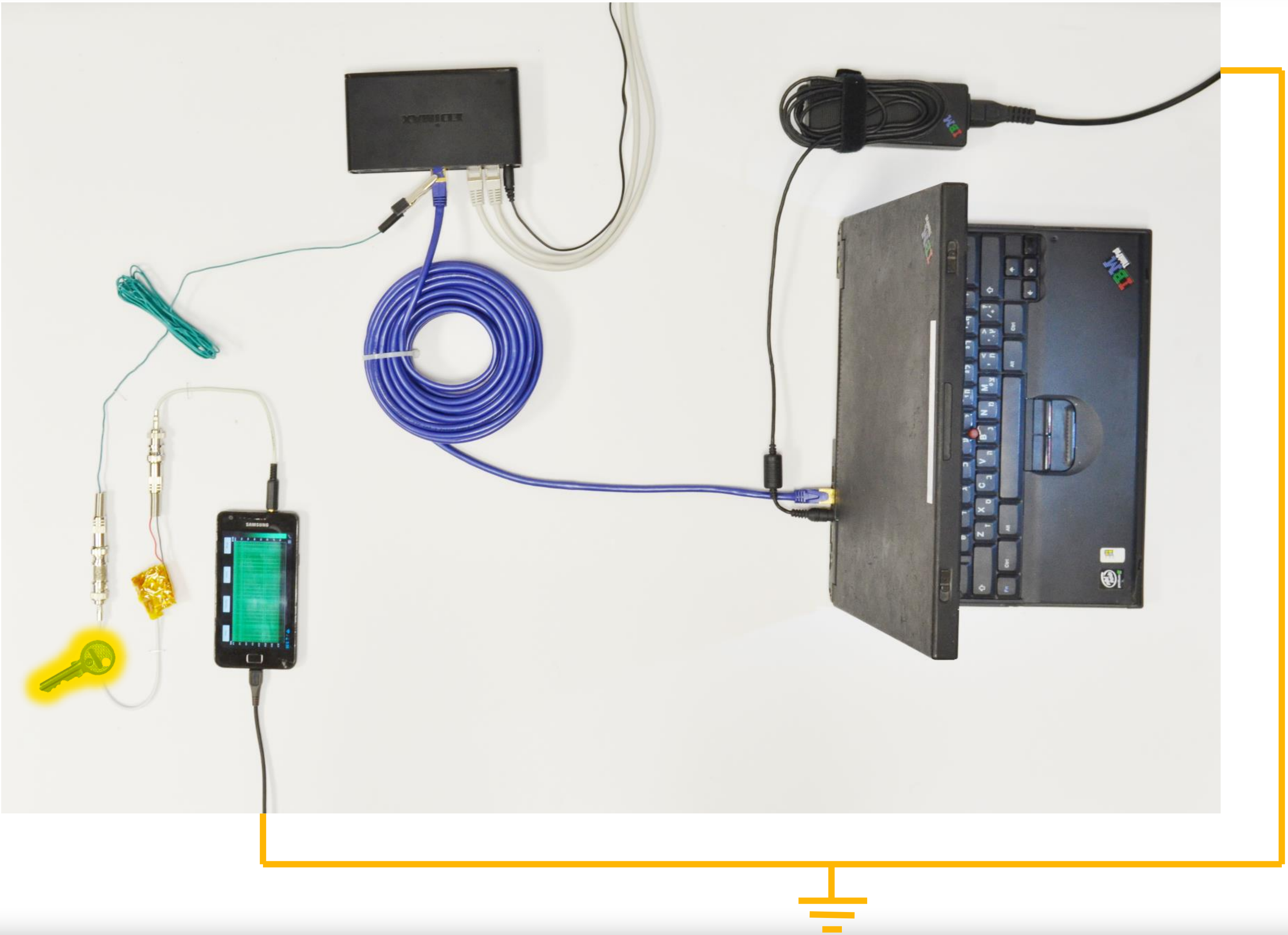

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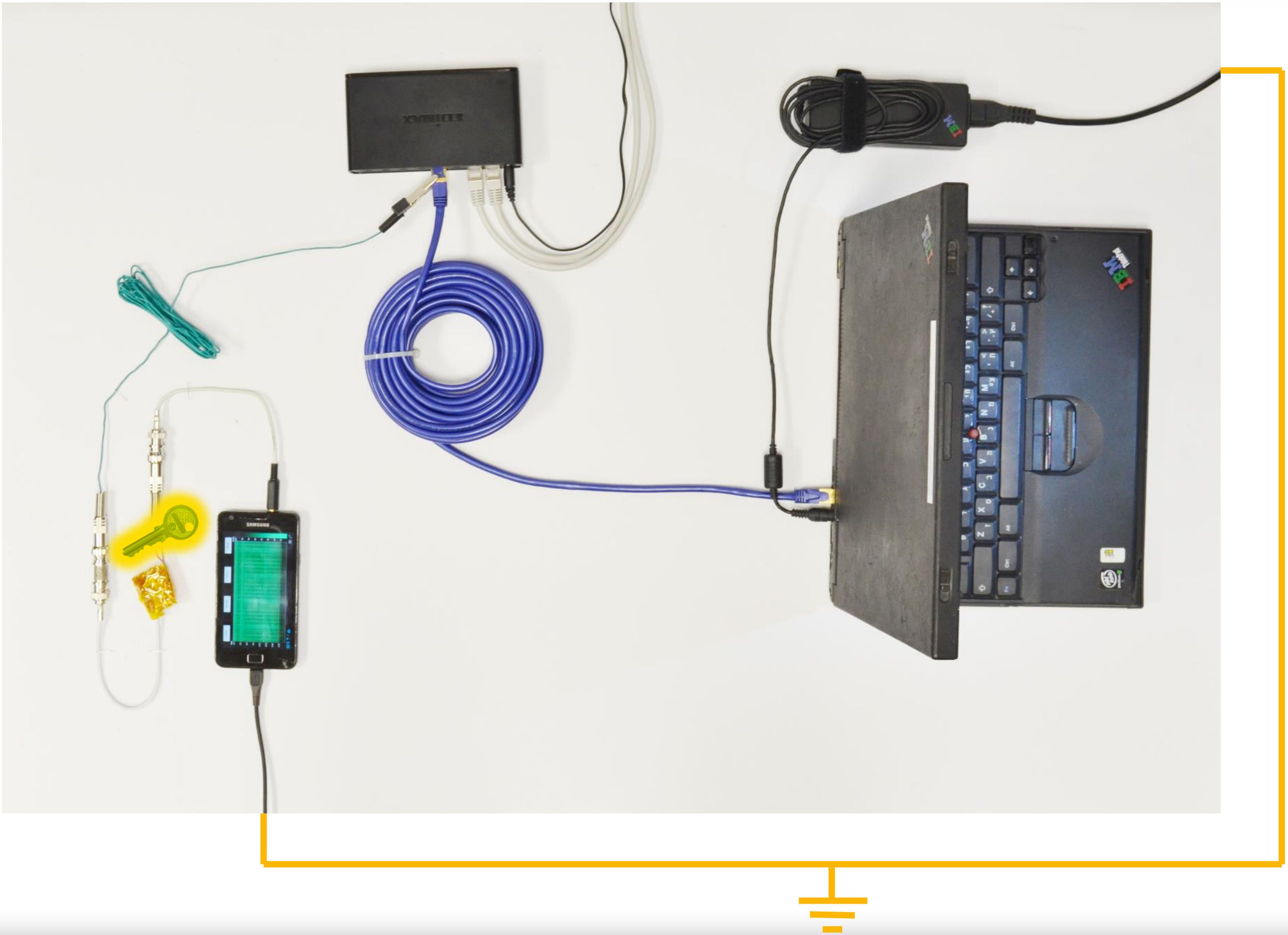

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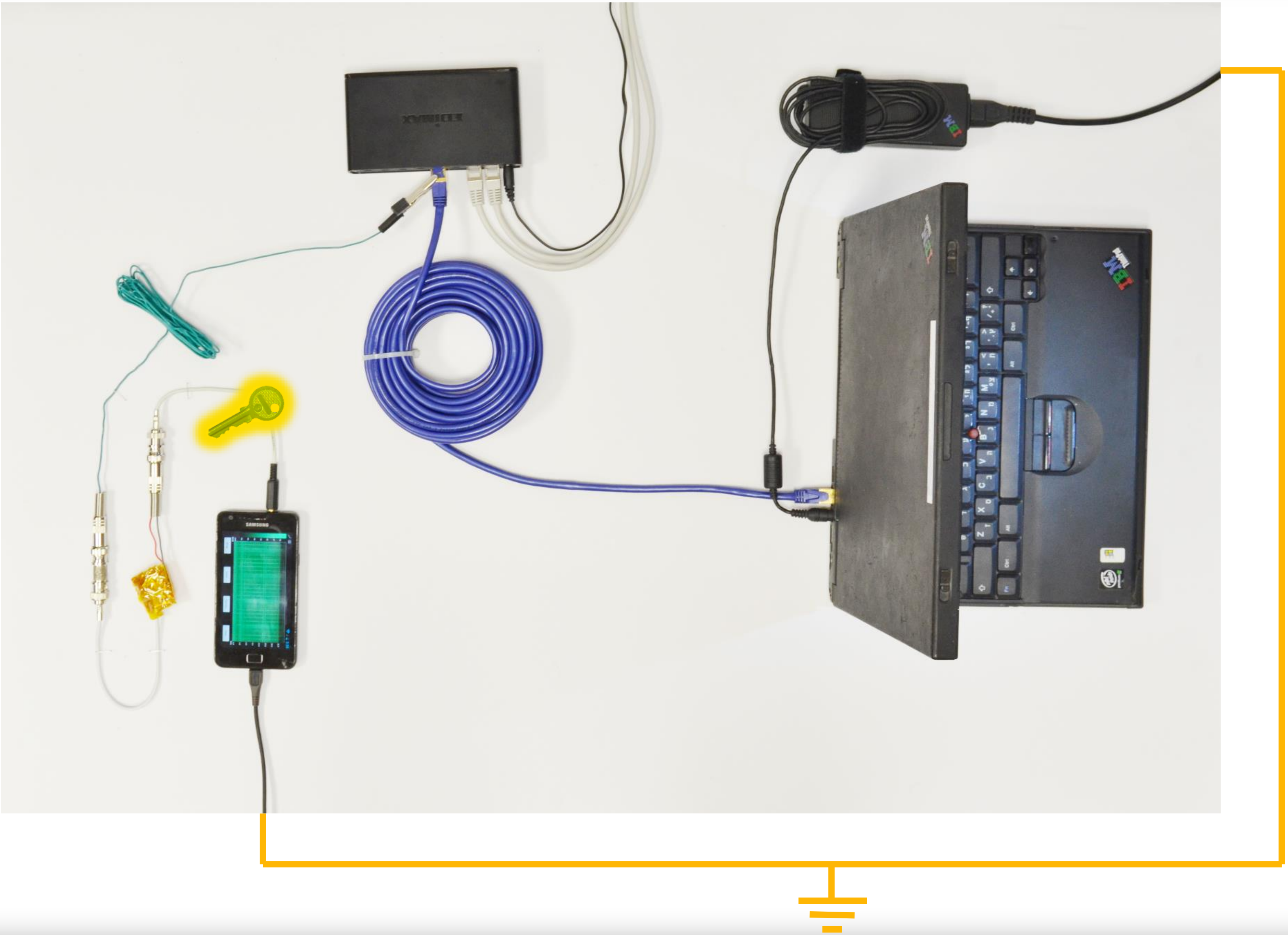

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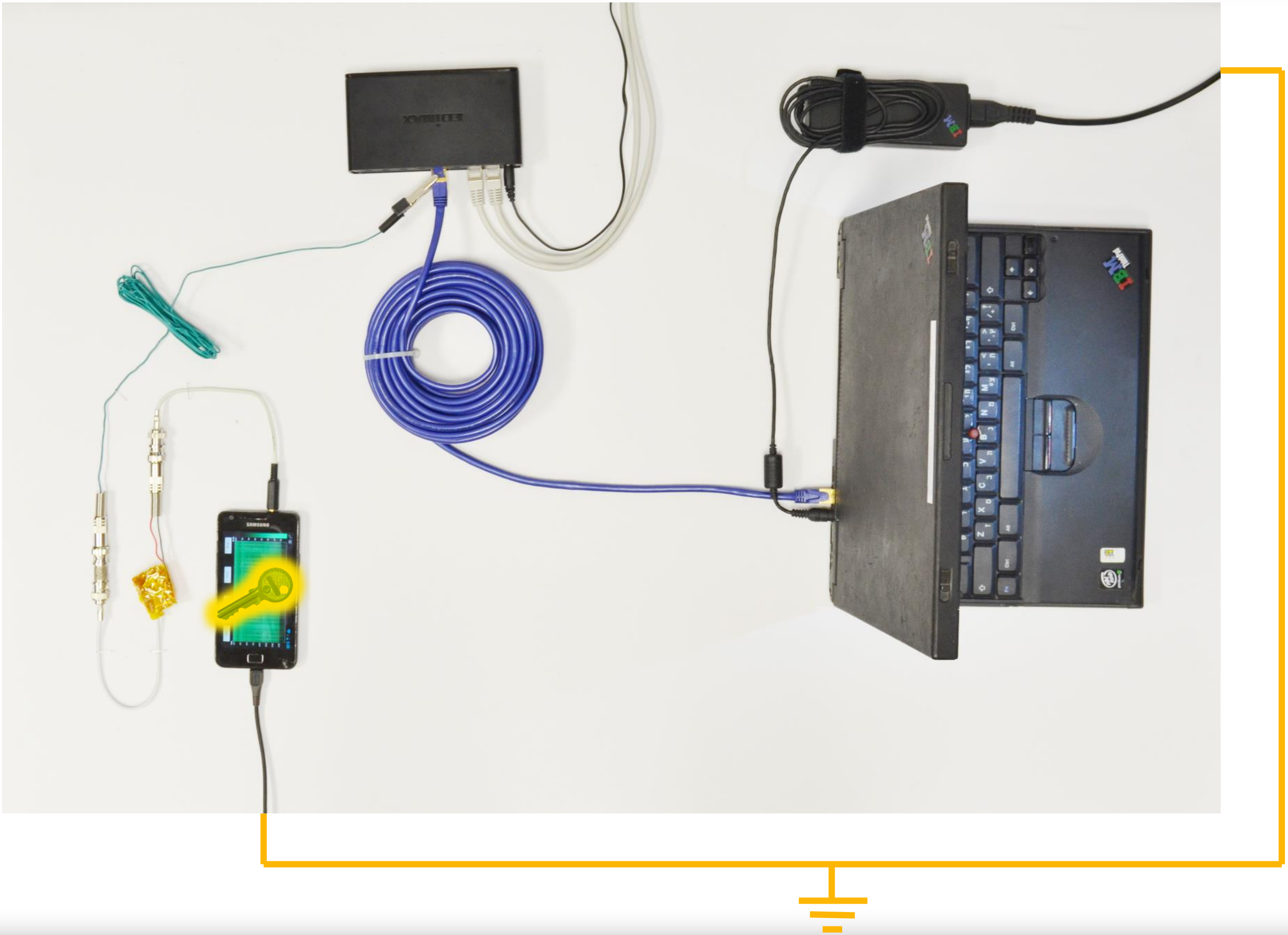

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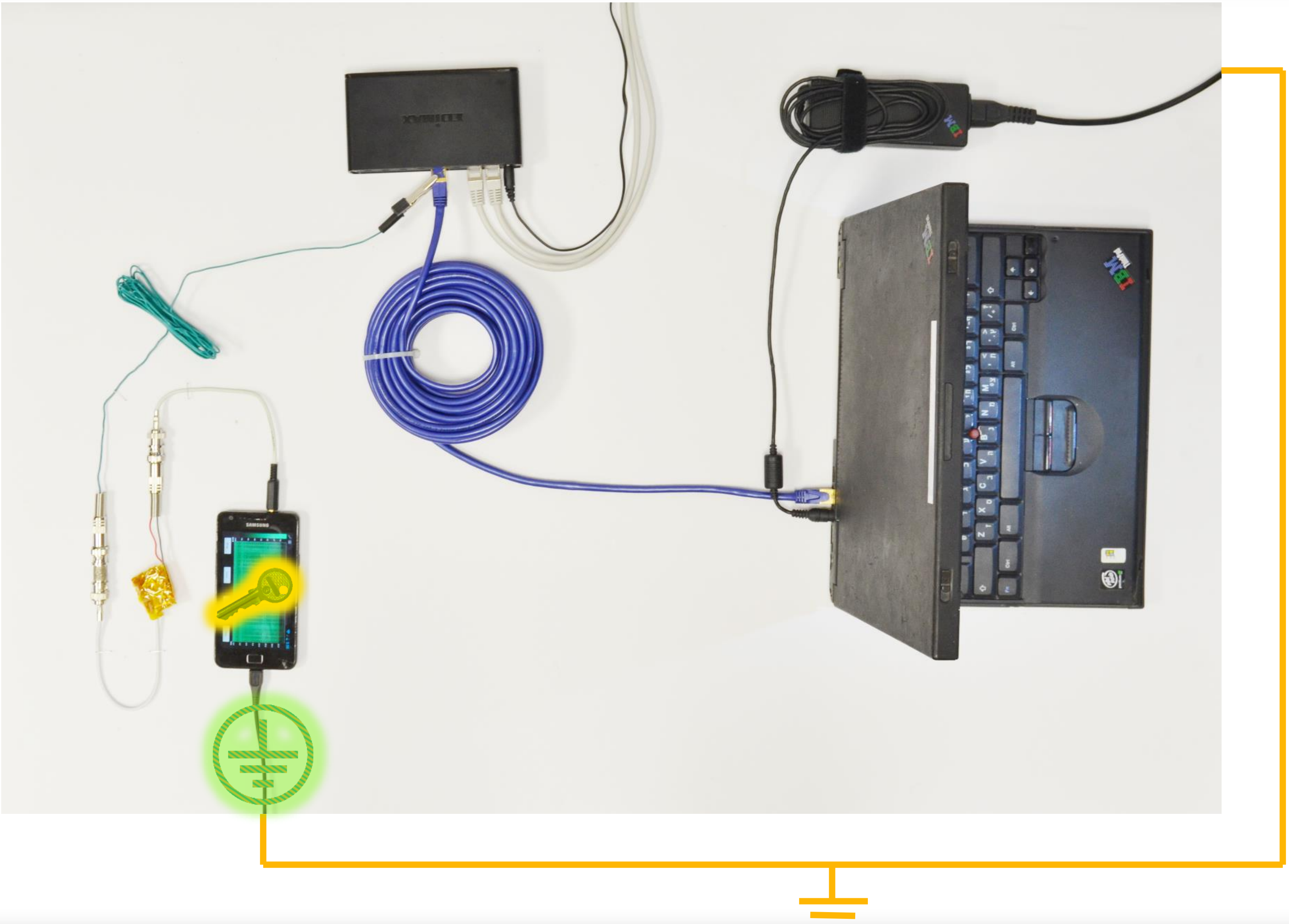

Countermeasures

Ineffective countermeasures:

1. Add analog noise
2. Parallel software load

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- x2 slowdown for ElGamal



Thanks!

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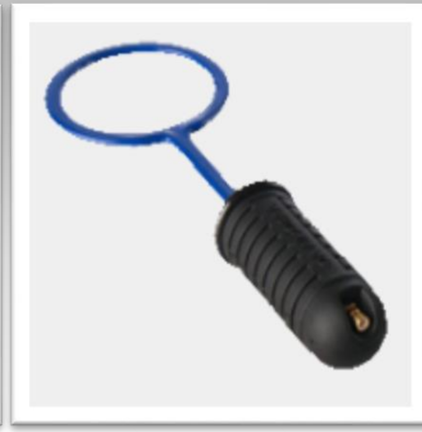

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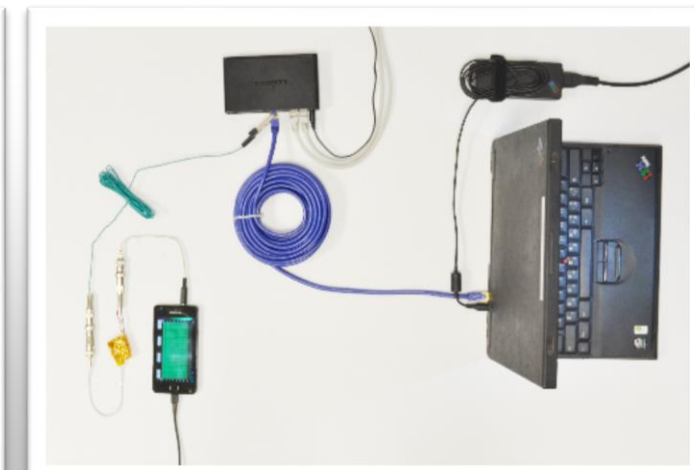


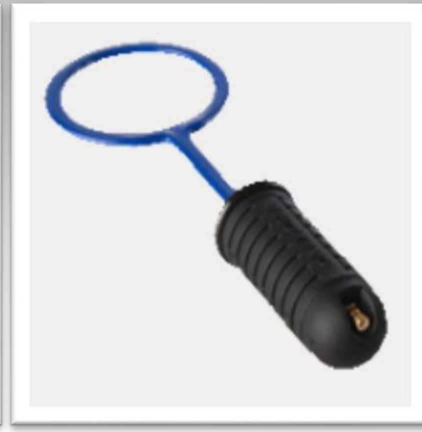


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